TEMPORAL VARIATION AND INTER-RELATIONSHIP OF MOVEMENT AND RESOURCE SELECTION OF RED DEER (*CERVUS ELAPHUS*) WITH RESPECT TO CLIMATE: A CASE STUDY

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ABSTRACT

Red deer (*Cervus elaphus*) is one of at least 31 herbivorous exotic mammals existing in New Zealand. All of these species have the potential to affect environmentral and production values. Reducing their impacts on their values, strengthening effective managements are important issues to a variety of agencies within New Zealand including the Department of Conservation (DOC), Ministry of Agriculture and Forestry (MAF), local and regional governments.

This research studied animal movement pattern and habitat use of 2 GPS-collared red deer in the Canterbury high country and found (1) deer movement was affected by climatic variables such as rainfall and temperature, which had positive or negative effect on it, and had seasonal variation; (2) deer had dominant landcover use categories, depending on climate, season, and individual characteristics (3) deer had different movement patterns in terms of hourly distances.

The purpose of the study is to draw accurate inferences from spatially explicit data for biosecurity managers and policy-makers through: (1) using global positioning system (GPS) as a tool to elucidate the application of GPS on red deer in wildlife management; (2) Animal Movement Analysis Arc View® 3.2 Extension under Arc View® Geographic Information System (GIS); (3) Animal movement analysis which used Generalized Additive Models (GAMs) to show how the movement of red deer was affected by different periods of time, seasons months and climatic variables (for example, rainfall and temperature).

CHAPTER 1: INTRODUCTION

1.1 Wild Animals in New Zealand

1.1.1 Wild Animal Species

New Zealand was isolated from Gondwana about 85 million years ago, and although mammals (monotremes) were present in Gondwana by this stage (Archer, et al., 1994; Parkes and Murphy, 2003) no terrestrial mammal fossils are known from New Zealand from this period, and only three species of bats were definitely present when humans settled about 900 years ago (Worthy and Holdaway, 2002). However, since human arrival, at least 31 species of introduced mammals have established wild or feral populations (King, 1990; King, 2001). Most mammals were deliberately released for a variety of reasons (King, 1990) The wild ungulates: eight species of deer (refer to Table 1), Himalayan thar (*Hemitragus jemlahicus*) and chamois (*Rupicapra rupicapra)*, the two lagomorphs: rabbits (*Oryctolagus cuniculus*) and hares (*Lepus europaeus*), and the five wallabies: dama (*Macropus eugenii)*, Bennett's (*Macropus rufogriseus)* , parma (*Macropus parma)*, brushtail rock (*Petrogale penicillata Penicillata)*, and swamp (*Wallabia bicolor)*) were generally introduced and released into the wild for hunting food and purposes. The feral animals: goats (*Capra hircus)*, pigs (*Sus scrofa)*, sheep (*Ovis aires*), cattle (*Bos taurus*), horses (*Equus caballus*) were imported as domestic stock or pets and subsequently formed feral populations when they escaped. Possums (*Trichosurus vulpecula)* were imported to start a fur industry. Some predators: stoats (*Mustela ermine)*, weasels (*Mustela nivalis vulgari)*, ferrets (Mustela furo), and hedgehogs (*Erinaceus europaeus*) were imported as biocontrol agents to control rabbits, in the case of the mustelids (*Mustela furo)*, or invertebrate pests in the case of the hedgehog (Parkes and Murphy, 2003).

None of these 31 mammal species has any legal protection in New Zealand in terms of control except where farmed properly, although they do have protection in terms of welfare under the Animal Welfare Act 1999. The ungulates and marsupials are defined, generally as pests, under the Wild Animal Control Act 1977, and the rodents, mustelids, feral cats and hedgehogs, as unprotected animals, under Schedule 6 of the Wildlife Act 1953. Rabbits and hares are not specifically defined under any act, but may (along with any other nominated species) be managed as pests under regional pest management strategies under the Biosecurity Act 1993 (Parkes and Murphy, 2003). Because none have any legal protection, any may be controlled by private landowners providing they do so by legal methods. Central and regional government may control mammals where they are convinced that it is worth controlling them. The goals that direct such action are largely described in the Conservation Act 1987 for central government and promulgated under the Biosecurity Act in regional pest management strategies for regional government. Restrictions on how anyone may control mammals are set in the Animals Welfare Act 1999 and by agency policies. The Pesticides Act 1979 defines who may use certain methods (particularly toxins). Most mammal species have some populations that are controlled as pests (Parkes, 1996), even if only indirectly by recreational or commercial hunting (Parkes, et al., 1996). The ubiquitous possum is controlled under both a national plan under the Wild Animal Control Act for conservation purposes, and under a National Pest Management Strategy as a vector for bovine tuberculosis. The only other species with formal national control plans are feral goats and Himalayan thar.

Since 1861, wild mammals have been defined and their management prescribed under a variety of general and specific laws, especially since 1930 when central Government began to organize concerted control of those species deemed to be pests. Generally, earlier laws tended to be prescriptive, and sometimes actually inhibited sustainable solutions to pest problems, for example, when control costs were not equitably shared, as with past rabbit control (Gibb and Williams, 1994).

The Conservation Act 1987 administered by the Department of Conservation (DOC) and National Parks Act 1980 stress the protection of indigenous biota (including the native bats and marine mammals) and ecosystems, and, by implication in the main act, essentially determines that introduced mammals are pests where they adversely affect these values. This view of introduced mammals is reinforced in two subsidiary acts administered by DOC (the Wildlife Act 1953 and the Wild Animal Control Act 1977). The Wildlife Act lists most introduced mammals in two schedules, declaring them to be either "unprotected" or "noxious and subject to the Noxious Animals Act". The unprotected mammals include the rodents, mustelids and the hedgehog, whose status as pests is determined by implication in the Conservation Act 1987. It also includes feral horses as unprotected wildlife, although the main herd of horses in New Zealand, the Kaimanawa herd, is given some de facto protection under a management plan (Veltman, 2001). The Noxious Animals Act 1956 has been repealed, and the animals listed in the schedule (most of the ungulates plus the marsupials) are now the focus of the Wild Animal Control Act 1977. Under this act, DOC has responsibilities for wild animals on land of all tenures, but in practice spends most effort on land it administers. The Crown retains ownership of all wild animals until the animal is legally taken or killed, which requires the permission of the landowner. This gives landowners de facto private property rights to the animals when they are resources, and is balanced by the "beneficiary pays" principles on private land under the Biosecurity Act when the animals are pests (Parkes and Murphy, 2003).

The Biosecurity Act, administered by Biosecurity New Zealand , a semi-autonomous body within the MAF (Ministry of Agriculture and Forestry), where it concerns management, control and eradication of unwanted pests and diseases should they get past the border, sets out the rules for establishing concerted action against species nominated in national or regional pest management strategies. Anyone can propose a pest management strategy. A national strategy exists to manage bovine tuberculosis (Tb), including approaches to manage the mammalian vectors of the disease, and many mammal species are listed in regional governments' pest management strategies (Parkes and Murphy, 2003). Essentially, these strategies have to determine whether the benefits of concerted action against the pest outweigh the costs (otherwise control is the responsibility of the landowner), and determine equitable allocation of the costs of concerted control between beneficiaries and "exacerbators", for example, those who contribute to the problem. Traditionally, the management agencies (mostly regional councils) have focused on mammals affecting production values on rateable land (for example, rabbits and vectors of bovine Tb). However, recently they have begun to manage or consider wider environmental and conservation benefits under the influence of a national Biodiversity Strategy (Parkes and Murphy, 2003).

The DOC also controls a variety of other pest species at much smaller scales under its island management schemes (where eradication of the pests is the usual aim), under its threatened species recovery plans (where control of the critical predators is the main task) and under its Mainland Island initiative (where all or most species are controlled). It is not known how much the DOC spends on mammal pest control, but a large part of its "Ecological Management" budget of $72.5 million per year is spent killing mammals (Innes and Barker, 1999). Regional Councils also control many pest species, particularly possums, as agents for the Animal Health

Board, and possums and rabbits under Regional Pest Management Strategies (Innes and Barker, 1999)

1.1.2 Impacts and Control

Conservation problems caused by introduced mammal species include the modification of plant communities (Veblen and Stewart, 1982), and predation on (King, 1984) or competition with (Leathwick, et al., 1983) native animals. Economic problems caused by introduced mammals include damage to agricultural crops (Houston, 1993) and plantation forests (Hughes, 1993), and transmission of disease, particularly bovine tuberculosis (Alspach, 1993).

Accurate information on the status and distribution of introduced wild and feral mammal populations is essential for agencies such as the DOC and the Animal Health Board (AHB) if they are to minimise the ecological and economic damage that some of these species cause. Comprehensive information on species distributions was presented by (King, 1990), but it was not then possible to draw distribution maps standardized across all species in size or level of detail. Some maps show accurate range boundaries (for example, for economically important species that had by then been well surveyed, such as feral goats), but many others could show only the general area within which a species might be found in a suitable habitat (King, 1990). In addition, many new populations of introduced mammals have become established in recent years, through deliberate liberations in areas well outside their previous ranges, even though such liberations are an offence under the Wild Animal Control Act 1977.

1.1.3 Control Agencies

The Ministry of Agriculture and Forestry (MAF) has overall responsibility for Biosecurity and Pest Management in New Zealand. One of their foci is on biosecurity issues at the border but the recently completed Biosecurity strategy for New Zealand gives them a leadership role in pest management activities. This includes ensuring that pest management roles and responsibilities are clarified, decision making is more transparent and improving national and regional communication and coordination. The Animal Health Board's mission is to eradicate bovine tuberculosis (Tb) from New Zealand, in order to protect New Zealand's access to export markets for dairy, beef and deer products. The DOC is responsible for the conservation of New Zealand's natural and historic heritage. The department manages animal pests, weeds and wildlife diseases across terrestrial, marine and freshwater environments. It does this on public conservation lands (one third of New Zealand's land area), on lands of other tenure where this supports the protection of public conservation lands, and in marine reserves. DOC also has broader marine protection responsibilities for the foreshore and seabed, and marine mammals.

Environment Canterbury (ECan) has region wide responsibilities for biosecurity and pest management and the DOC also have responsibilities for pest control, nationally as well as on its estate.

1.2 Introduction and Spread of deer in New Zealand

Red deer were first introduced into New Zealand by English settlers from 1851. Other deer species (fallow, sambar, sika, wapiti, white-tailed deer and moose) soon followed from 1864 to 1909. The Wapiti were sent by American President Theodore Roosevelt in exchange for native NZ birds and Tuatara. Wapiti are the largest member of the deer family and in NZ can be found on the lower West Coast of the South Island**.** Table 1 shows exotic deer species introduced to New Zealand from 1850 to 1920. However, when deer were first introduced in New Zealand is unclear – estimates vary from 1851 to 1871. What is certain is that it was settlers wanting to hunt deer for sport who introduced deer (John and MacGibbon, 1986). New Zealand's temperate climate proved to be ideal for deer and they thrived (not unlike other introduced flora and fauna). Deer in their new habitat grew to a size that was well beyond what was known in Britain (Nixon and Duncan, 2004). The main reasons for this were that New Zealand provides abundant food to them in the form of a luxuriant, varied, evergreen vegetation, especially winter browse with moist and mild weather; deer had protection from hunting in the early days and became early maturity in New Zealand. Once more, a younger breeding age in females were absence of predators, pests, and diseases; Areas into which deer could escape and remain hidden were too vast and heavily forested for them to be easily control, and large number of herds established (Nixon and Duncan, 2004).

Provision of sport and meat for early settlers that contributed a "touch of home" was the reason for red deer introductions, but, once the herds became well established, the prospects of substantial license revenue from overseas sportsmen gained importance The increase and spread of red deer were remarkably rapid (King, 1990). By the late 1940s Red deer had established themselves throughout much of the North and South Island, occupying 44% of New Zealand's mainland. The other species had formed established herds in localised parts of the country. Most of the local deer

Table 1 Summary of Introduced *Cervid* Species in New Zealand

Species	Origin	No Released	Year & Places Released
Red Deer (*Cervus elaphus*)	England and Scotland	>250 About 1000	1850-1919, Nelson. 1923, North, South, and Stewart Islands.
Wapiti (*Cervus Canadensis*)	USA	2 18	1873, Kawau Island in March 1905, George Sound
Sika Deer (*Cervus Nippon*)	Northern China Northern China Hamburg	3 7 6	1885, Otekaiki Estate, Oamaru 1904,Taharua, Taupo 1905, Kaimanawa State Forest Park
Sambar Deer (*Cervus unicolor*)	Sri Lanka Sri Lanka Scotland Scotland	2 1 8 7	1875, Carnarvon Estate, Rangitikei 1876, Morrinsville, Waikato 1907, Galatea District 1915, Galatea District
Rusa Deer (*Cervus timorensis*)	New Caledonia	8	In November 1907, Rotorua
Axis Deer (*Cervus axis*)	Calcutta (India) Calcutta (India) ? London London	7 2 3 6 6	1867, Bushey, Otago 1893,Kapiti Island 1902, Quail Island 1907, Wellington, Tongariro 1908, Dusky Sound
Fallow Deer (*Dama dama*)	Surrey Australia England Tasmania London	1 4 12 ? 28	1864, Nelson 1867, Tapanui, Otago 1869, Tapanui, Otago 1870, South Island 1876, Waikato, Wanganui
White-tailed deer (*Odocoileus viginianus*)	USA	4 19	1901, Takaha Valley, Nelson 1905, Stewart Island, Lake Wakatipu, Motueka
Moose (*Alces alces*)	Vancouver Vancouver	4 10	1904, New Foundland 1909, Wellington

Adapted from (Donne, 1924; King, 1990)

populations in New Zealand have passed through a classic irruption (Holloway, 1950), typically comprising three phases: an initial usually rapid increase in number(Pre-peak phase); a period of sustained high density (peak phase) ; and then a natural decline in numbers (post-peak phase), caused by the progressive in the quantity and quality of food available per capita (King, 1990).

The reason for red deer introductions, but, once the herds became well established, the prospects of substantial license revenue from overseas sportsmen gained importance The increase and spread of red deer were remarkably rapid (King, 1990). The short term impact of uncontrolled wild deer populations on New Zealand forests and grasslands soon became clear, as did the economic impact - damage to agricultural crops and plantation forests, and the transmission of disease, most notably Bovine Tuberculosis (DOC, 2002a).

In the 1960s, increasing wild deer numbers in New Zealand was found that it benefits both of the development of a feral venison export industry and pests management, centred largely around Fiordland National Park and other heavily populated areas of the North and South Island. The growing feral venison export industry led to the emergence, in the late 1960s, of deer farming on private properties. Today, 40 years on, there are 5078 deer farms spread throughout the country and the deer industry represents an important economic activity for New Zealand (DOC, 2002a)

1.3 Red Deer Biology

Red deer are the most widespread wild deer species in New Zealand farmed primarily for velvet and venison, and also are common over most of the country except for some isolated areas and occur almost wherever any land is in bush and on scrub areas of large farms[1]. The adult male Red deer (stag) stands about 116cm at the shoulder, the female (hind) is smaller at about 100 cm and is of lighter build. A mature stag weighs about 130 kg. Colour changes from a glossy reddish brown in summer to a drab grey-brown in winter. Both male and female have a straw-coloured rump patch and the underside of the belly is creamy. Only the stag has antlers, which are replaced each year[1].

They are socially gregarious in nature, living in herds of hinds and young; and separate groups of stags (Challies, 1990; Daniel and Baker, 1986; John and MacGibbon, 1986; Wodzicki, 1950.). Stags and hinds live in separate herds for most of the year, each keeping to a well-defined territory. Deer in low forest live in small groups but highland deer usually live in larger herds, moving up the hillsides by day to feed and shelter in the deeper heather or woods at night (Wodzicki, 1950). Summer and winter territories are different. In winter, the herds move to lower ground where there is more shelter, and in summer, they keep to the higher slopes preferred habitat: Coastal lowlands to high alpine areas. Both males and females are sexually mature at sixteen months; although young males do not usually mate until they are a few year old and can compete with more mature males (Senseman, 2002). The rutting season takes place from about mid-March until the end of April, gestation generally lasts between 240 and 262 days and results in a single birth (twins are rare). This low annual production is offset by a high investment in protective maternal care. At birth, calves weigh around 15 to 16 kg and have creamy spots on their back and sides. Their hooves are soft. Just after birth, a cow and her calf will live alone for several weeks. At 16 days, the calf is able to join the herd, and weaning is completed within 60 days. Female red deer protect their calves by hiding them in a secluded area during their first few weeks of life. They nurse and protect their young through their first year of life. Male elk do not contribute to the care of their young (Senseman, 2002).

During the rut, stags wallow in muddy pools, into which they urinate and defecate. The covering of mud accentuates the smell given off by a rutting stag and can give it a larger, darker appearance. Wet and dry wallows are used occasionally by both sexes at other times of the year, particularly during late spring when they are shedding their winter coat (Austin, et al., 1992).

1.4 Public Perceptions of Introduced Animals and Their Management

New Zealanders already have mixed, or contradictory, and often passionate views on the value of introduced mammals (Johnston, 2000; Lark, 2000), and even where they agree on the status of a species as a pest they often disagree on how to manage them, for example, debates over the future use of genetically modified biocontrol agents or the current use of toxins (Green, 2003; PCE, 2000b). At the least, these debates place constraints on how pest managers control mammal species. Of course, perceptions have changed about which species are pests. For example, despite some opposition from biologists and managers of game birds, mustelids were enthusiastically imported and released in the 1880s in an attempt to control rabbits. Government began to have second thoughts about the wisdom of this by 1903 but did not remove all legal protection from the species until 1936, culminating in 2002 with a proposed ban on the sale and breeding of domestic ferrets (King, 1990). Similarly, the legal status of possums has shifted from one of complete protection, through licensed trapping as a resource for fur, to a pest—but one that can provide some resource value. King (1996) categorised public perceptions (within the wider context of views on conservation issues) into four groups: idealists, traditionalists, pragmatists, and commercial users. The idealist would exterminate them all, the traditionalist would accept those that are useful, the pragmatist would accept those that are established, and the commercial user sees them as something to exploit. We

[1]www.nrc.govt.nz/pests.and.weeds/pdf/animal.pests accessed on 28 July, 2005

can see all these views, for example, in debates over the status of wild deer. The idealist, largely represented by environmental groups in New Zealand, dreams of a day when a technique will become available to eradicate entire pest species. The traditionalist is largely represented by the hunting fraternity who often have a "monarch of the glen" view of deer, and while they say they are happy to limit their numbers, generally battle to keep the idealists and especially the commercial harvesters at bay. The pragmatists are largely represented by scientists and managers who think deer are here to stay, but that they should be managed to limit their spread and damage. The commercial exploiter of deer is represented by the harvest industry who, in the absence of property rights to the animals, cannot arrange any maximum sustained harvest and so take what they can afford to get (Nugent, et al., 2001a; Parkes, 1996).

In 1996, DOC began a consultation process in an attempt to develop a national deer control plan. A series of reports was produced to show the evidence (both biological and management) on all sides of the argument on how to manage deer (DOC, 1997), but views remained polarised as the process of consultation developed. The Department abandoned this attempt to develop a national plan, but promulgated a policy statement reiterating the official view of wild deer as pests, noting the main management aims of limiting their spread and controlling densities in high priority areas. However, it has recently revived plans to constructively engage the competing interest groups. Recreational and commercial hunting is encouraged, but as a control tool rather than an end in its own right. Legally, there is nothing to stop recreational hunters attempting to manage deer and other game animals themselves, especially in areas with low conservation values. The recreational hunters already do this to some extent for fallow deer herds in the Blue Mountains (Otago) and at Woodhill (Auckland) and for sambar deer in the Manawatu (Nugent, et al., 2001a), for example, for species not commercially harvested. However, for commercially harvested species such as red deer, hunting organisations cannot restrict their commercial competitors, let alone other recreational hunters. The government sees such a role for itself as being inconsistent with its policy that views the animals as pests (DOC, 2001) and so will not regulate hunters for that purpose. The official view of introduced mammals as pests is not entirely shared by the public. Fraser (2001) surveyed a sample of New Zealanders on their perceptions of introduced animals. Most (71–94%) considered the smaller mammals as pests, but their views of the larger ungulate species were more circumspect. Only 4% considered deer as pests, with the remainder being evenly split and seeing deer either as both pest and resource depending on circumstances, or as resource alone. The view of the smaller mammal species as pests confirms earlier surveys of particular mammal species. Fitzgerald et al. (1996) surveyed peoples' views on possums and their control. Most (80%) agreed that possums were a threat to conservation and/or to livestock as a disease risk, and a majority (70%) recognised possums posed a risk to our overseas trade. However, despite the consensus that possums were a pest, views on how to manage possums rarely reached such levels of agreement. A majority agreed that shooting, using possum-specific poisons, and trapping were acceptable, while only a minority found the use of 1080 and various biological control methods to be acceptable. Of the biological control methods, a genetically engineered organism that killed only possums was favoured over imported biocontrol viruses, bacteria, or parasites, and biocontrols targeting fertility were favoured over those increasing mortality. The Parliamentary Commissioner for the Environment (PCE) also reviewed New Zealanders' perceptions of possums and their control and also noted the conflict about how to manage the pest (PCE, 2000a). The Commissioner concluded "something was seriously wrong at the interface between science, regulatory agencies and communities", particularly with respect to the development of new control technologies such as genetically engineered products, and recommended research aimed at understanding how society judges the risks, costs, and benefits of pest control options. The PCE clearly believed that merely providing information to society is insufficient to change the paradigms of protagonist groups—in fact such information often further polarises views as the protagonists seize on the facts that suit their case and ignore the rest Surveys of public attitudes towards rabbits and their potential biocontrol agent rabbit haemorrhagic disease (RHD) were carried out using focus groups and telephone questionnaires in 1994 and 1996 (Fitzgerald, et al., 1996; Wilkinson and Fitzgerald, 1998), for example, before and during the proposal to release RHD. Results from 275 respondents participating in both surveys showed that, despite the efforts of the proponents of importing RHD, the level of support fell from 54 to 47% over the 3 years. A third survey taken after the illegal introduction of RHD in 1997 would be interesting now that the actual benefits and costs of the disease are more clear (Norbury, et al., 2002; Parkes and Warburton, 2002). In 2001, seven facilitated focus group discussions, four groups of the general public and three interest groups, were conducted to examine perceptions of stoats and other mustelids in New Zealand. Stoats were generally viewed negatively, although the four public groups knew very little about the species compared with the interest groups. Views on how to control stoats favoured trapping over use of toxins such as 1080, although some people acknowledged poisons might be a necessary tool in the absence of alternative methods. There was clear discomfort with new potential biocontrol methods, especially those based on genetically engineered organisms (Fitzgerald, et al., 2002).

1.5. Red Deer Management

1.5.1 Reasons for Management

1.5.1.1 Biodiversity Impacts and Diet related Impacts

Deer were introduced into New Zealand in the 19th century and are now considered a serious threat to conservation of forests administered by the Department of Conservation (Holloway, 1993; Nugent and Fraser, 1993). It was soon noticed that deer were reducing the density of understorey vegetation in some forests and altering composition by preferentially browsing certain species (Caughley, 1983; Cockayne, 1926; Walsh, 1892) because they are prolific breeders, they seriously damage native bush and they are potential carriers of bovine tuberculosis. After the multiple introductions of deer into New Zealand in the late 19th century, it was recognized that selective browsing was capable of eliminating subcanopy hardwood species from forest understories (Cockayne, 1926; Walsh, 1892). Later studies of the post-irruptive phase of deer colonisation showed that browsing was also capable of suppressing the regeneration of beech forest canopies in some regions (Holloway, 1950; Riney, et al., 1959). The browsing habits of these animals interrupted and in some cases hindered the regrowth of native forests and damaged tussock grassland. The deterioration of vegetative cover in turn accelerated erosion and so indirectly affected the country's economy (McLintock, 1966) Beech (*Nothofagus*) species are regarded as being more browse resistant than common subcanopy hardwood species such as *Griselinia littoralis* (broadleaf) and *Raukaua simplex* (Coomes, et al., 2003; Forsyth, et al., 2002; Husheer and Robertson, 2005). Beech forests are also less vulnerable to other introduced browsers such as brushtail possums, which tend to browse on flowers, fruits and foliage of adult trees other than beech (Cowan, 2001; Nugent, et al., 2001b). Nugent *et al*. (2001) showed that even where deer and possums browsed on the same species; deer had greater impacts on regeneration by preferentially browsing on entire cohorts of seedlings rather than less vulnerable trees. It is now widely recognised that the composition and regeneration of most New Zealand forests reflects decades of preferential browsing of palatable species by deer (Husheer and Frampton, 2005; Veblen and Stewart, 1982).

Deer are a serious pest on public conservation land. There is clear scientific evidence that deer pose a significant and ongoing threat to New Zealand's native forests and grassland ecosystems. Deer prevent regeneration of favoured plant species, which causes significant changes to the structure and composition of native ecosystems. At critical sites, non-replacement of canopy species can lead to canopy collapse.

There is no evidence that equilibrium has been reached between deer and the native ecosystems they inhabit[2]. Deer continue to inhibit forest regeneration even at low density. Because many native plant species can live for hundreds of years, it will be many decades, if not centuries before the longer-term adverse impacts of deer on native forests become clear. In at least some areas, deer induced changes to forests and flow-on effects to other native species are likely to be irreversible[2].

Understanding the diet and diet preferences of introduced ungulates is important in managing their impacts. Accurate information on the diet of a herbivore provides information about potential monitoring measures and is therefore of considerable importance when considering and designing control operations (Cochrane, 1994). But, the major problem faced in assessing the effects of introduced browsing mammals is the difficulty in separating the effects of natural processes from browsing impacts on vegetation (Jane, 1994).

Recent analysis of diet studies relevant to red deer (Cochrane unpub. Data) confirm that deer consumes an array of vegetation. Dependent on availability Cochrane suggests that the following vegetation groups are consumed in these quantities: herbs(25-44%), trees (17-31%), shrubs (10-17%), Ferns (10-17%), Lianes (3-8%), Poaceae (3-7%), and Conifers (0-5%) (M^{c}Kenzie, 2004).

1.5.1.2 Impacts and disease related Impacts

Wild deer are one of the hosts and vectors (carriers) of the disease Bovine

[2] **www.doc.govt.nz accessed on 28 July, 2005**

Tuberculosis (TB) (*Mycobacterium bovis)* affecting livestock (cattle, pig and herds of deer) through the country, even humans. Bovine tuberculosis is one of New Zealand's most serious animal health issues.

Deer are considered to be a pest by the Animal Health Board and other agencies responsible for Bovine Tuberculosis (TB) control. The fact that deer can disperse long distances means that they have the potential to spread TB and re-infect possum populations from which the disease has been eliminated. Management of bovine Tb in New Zealand is subject to a National Pest Management Strategy under the Biosecurity Act 1993, implemented and administered by the Animal Health Board [2].

Mycobacterium bovis was probably introduced into New Zealand with cattle imported in the early 19th century. A tuberculosis control programme was introduced for cattle in 1945. However, the control of tuberculosis in cattle and deer in New Zealand over the past two decades has been hampered by the presence of an important wildlife reservoir: the Australian brushtail possum. While the Ministry of Agriculture and Forestry has suspected the importance of this source of infection for some time, scientific proof has been lacking until recently. A new control programme is currently being finalized with the following objectives, to reduce the prevalence of herd infection in vector free areas to internationally accepted levels, to prevent the establishment of tuberculous vectors in new areas, to decrease the number and size of existing areas where tuberculous vectors exist, and to encourage landowners to take action against tuberculosis on their properties and in their herds (O'Neil and Pharo, 1995).

The Animal Health Board (AHB) is responsible for managing and implementing the National Pest Management Strategy for Bovine Tuberculosis (NPMS) in New Zealand. The NPMS was approved by the Government in 1998 and amended in 2004. It provides for measures to control tuberculosis (Tb) in cattle and deer herds, which include: Surveillance for Tb in cattle and deer herds, and wildlife vectors. In 1997 the DOC convened a working party to advise on development of a deer control plan. Public submissions on a discussion document prepared by the working party reflected two significantly different and strongly held views.

Hunting organisations and most farming organisations expressed the view that eradication of deer is neither possible nor desirable and their impacts on native ecosystems can be minimised by managing deer as a game resource. Despite the fact that these one or the other of these views tended to be reflected in most submissions, the proposed goals, strategic directions and priority rankings outlined in the discussion document were acceptable or partially acceptable to most submitters who responded to questions on them.

The DOC will take a targeted control approach, which is designed to achieve clearly stated outcomes for the protection of indigenous plants and ecosystems.

Unlike the Department's national possum and goat plans, this policy statement does not prescribe areas where deer will be controlled over the next ten years. Priorities for deer control will be assessed using a decision support system that is being developed by the Department, which will allow control of deer, possums, goats and other threats to be better integrated. The proposed approach will not affect management of deer on private and Maori land, except for control of new and isolated populations and regulation of deer farming. Regional and national pest management strategies (RPMS and NPMS) will continue to be the main mechanisms for controlling deer on private land, where these are in place. The Department will retain the ability to use powers under the Wild Animal control Act to enter onto land to control deer causing damage to native flora and fauna[2].

1.5.1.3 Deer pest management strategies

Pest mammals are managed for three broad purposes (Parkes and Murphy, 2003): to protect indigenous species and communities, to reduce vectors of Tb, and to protect production values, and, depending on the species and where it lives, these purposes may overlap. Whatever the purpose, there are two positive strategic options to manage pest mammals: (1) where a one-off management action provides a permanent benefit (eradication or some forms of biological control); or (2) where the management action has to be sustained in perpetuity to achieve a benefit (sustained control or fencing). A third option is to “do-nothing”.

Most management of mammals to ameliorate their impact on conservation values is conducted by DOC. The Department administers about 78 000 km² (29%) of New Zealand, and all of this land on the main islands has at least one species, and up to 15 species (in the Two Thumb Range in Canterbury) of introduced mammals present; usually at least one ungulate, one rodent, one mustelid, and one marsupial species. The Department manages mammals at an estimated annual cost of c. $40

[2] **www.doc.govt.nz accessed on 28 July, 2005**

million, or 23% of its budget in 2001 / 02 (DOC, 2002b).

Local control or management plans have been developed by DOC conservancies for some mammal species, such as the dama wallaby population near Rotorua (Anon., 2002b), the feral horses of Kaimanawa (DOC, 1996), deer in the Murchison Mountains (Crouchley, 2000), and for new populations of deer in Taranaki and Northland (Fraser, et al., 2003). In 2001 / 02, $8.2 million was spent on the control of "other animal pests", which included cost allocated for the thar management noted above, for deer and feral horses, and for a range of pest fish species and wasps. The campaign to eradicate recently established deer populations is interesting because it is a multiagency project with an annual budget of $185,000, involving DOC, Northland Regional Council, Agriquality New Zealand, the Animal Health Board, and farmer groups. It aims to identify and eradicate all new populations of deer in Northland. It has removed most of the estimated 140 deer from the wild in Northland, leaving perhaps fewer than 10 animals (a few red deer at Mangakahia, and a few sika deer at Russell) in the wild (Fraser, et al., 2003). Equally important, the project has reduced the number of farmed deer escaping into the wild, discouraged illegal liberations by demonstrating their low chance of success, and accounted for all reported escapees in 1999/2000 (McKenzie and Gardiner, 2000).

1.6 GPS as a Tool

Global positioning system (GPS) radio-telemetry is a relatively new technology that has become an important wildlife research technique. The principal advantage of GPS radio-telemetry over more traditional methods, such as VHF radio-telemetry, is the consistent accrual of large numbers of locations per radio-collar (or animal) through automated tracking (D'Eon and Delparte, 2005). While increasing the number of locations per animal results in higher accuracy of individual home range and habitat use parameter estimates (Girard, et al., 2002; Otis and White, 1999) researchers must address potential error and bias in raw GPS radio-telemetry data (D'Eon, et al., 2002; Frair, et al., 2004; Moen, et al., 1996). With any new technology, rigorous testing must be a priority in order to ensure that accurate conclusions are reported, and GPS radio-telemetry is no exception.

Telemetry can help give us a better understanding of animal movements. Telemetry has helped us elucidate the pattern of migration animals follow, how far and how fast they move, the geographic areas they occupy, and whether individuals vary in these traits so as to provide some data of wildlife for the management. With radiotelemetry, knowledge about timing, duration, and route of migration became possible. Detailed knowledge of migration and differences among individuals could enhance our understanding of the energetics of deer migration and what role migration or energetics plays in the reproductive success of individuals and thus in the productivity of migratory deer populations. Additionally, fine-scale details of migration could contribute insight to understanding behavioral aspects of migration because it takes deer through unfamiliar terrain where they may be most vulnerable to predation (Nelson, et al., 2004).

Radiotelemetry has provided previously unavailable insights into the activity, habitat use, and survival patterns of many wild animal species (Amstrup and Durner, 1995; Amstrup, et al., 1986; Craighead, 1998; Craighead and Sumner, 1971; Craighead, et al., 1976; Erickson, et al., 2001; Garner, et al., 1990; Kenward, 2001; Pollock, et al., 1989; White and Garrott, 1990; Whitman, et al., 1986; Winterstein, et al., 2001). Analysis of movement patterns, however, has been the most common and persistent use of radiotelemetry data. With telemetry, we have learned when animals were active, how far and how fast they moved, what areas they occupied (their utilization distributions or UDs) (Kernohan, et al., 2001; Winkle, 1975), and whether they varied in these traits, among individuals or time frames (Amstrup, et al., 2000; Amstrup, et al., 2001a). Radiotelemetry descriptions of animal movements are retrospective. Management decisions such as those related to harvest regulations or industrial development, on the other hand, are forward looking. Managers are interested in where animals will be in the future, how many will be in particular locations and hence might be impacted by human activities, and how numbers or distributions may change among seasons. Heretofore, methods of interpreting radiotelemetry data have failed to provide probabilistic answers to such questions.

Attempts to convert radiotelemetry data to probabilistic information necessary for management are inchoate. Even in the chapter of their recent book focusing on future needs of radiotelemetry, Millspaugh and Marzluff (2001) did not emphasize the need to make radiotelemetry data more relevant to daily needs of managers. Typically, animals have been grouped subjectively (often according to where they were captured), or according to where they are observed at particular times (e.g., breeding, calving, nesting) of the year. Polygons and other shapes have been drawn around clusters of locations to indicate individual, herd, or population UDs. Such approaches might aid population management if there never was overlap in the movements of animals from the different groups or populations. Usually, however, there is extensive geographic overlap in UDs. Individuals also commonly move among population units and occasionally move across the ranges of many others to make new homes (Amstrup, et al., 2000; Bethke, et al., 1996; Durner and Amstrup, 1995). Geographic overlap in movements of individuals and groups they compose has not been quantified because of the inability to assign estimates of uncertainty to descriptions of animal movements (Armstrup, et al., 2004).

1.7 Animal Movement Analysis Software

The Movement extension is a collection of over 40 functions to aid in the analysis of animal movement data[3]. The motivation for the creation of this program was the absence of a collection of tools with real integration into a Geographic Information System (GIS). In addition, several functions in this program had not been implemented before or were specifically developed to address author specific research problems. The software program was chosen for development because of the high degree of integration of its GIS environment, the ability to work with a wide variety of spatial data formats, compatibility with many computer platforms, and the capability of its object oriented scripting language Avenue. The ability to cleanly load and unload code developed for specific functions (extensions) was an added benefit. The use of Avenue and has both costs and benefits. Implemented through a scripting language, several of the functions are significantly slower than compiled code would be. However, most functions work as fast as or faster than similarly compiled programs. On the benefit side the program has full integration with all other Arc View functions and extensions. The Movement extension works in multiple projection systems, uses the selected records (enabling complex queries or selections), inputs point and attribute data in many formats, and will integrate with many types of spatial data[3].

Arc View Tracking Analyst provides an ideal tool to track and monitor wildlife movements. Not only can scientists monitor wildlife positions and attributes as they change, but they can also replay the past positions of the animals to perform detailed analysis of daily movements or migratory patterns. The ability to study the animals' movement through time in Arc View Tracking Analyst is further enhanced with the

[3]**http://www.absc.usgs.gov/glba/gistools/animal_mvmt.htm**

Table 2 Tools implemented in the Animal Movement Analyst Extension.

1 2	Name of Function	Description
V M	Create Polyline from Point File	Creates a Polyline Theme connecting points in the order of the records
V M	Animate Movement Path	Animates the movement path with the user-selected values
V T	Display Movement Path	Moves through the movement path one position at a time via mouse clicks
V M	Set Movement Path Variables	Allows user to set the graphics and field display for the two path functions
V M	Static Interaction*	Analyzes spatial correlation between two individuals without regard to time
V M	Dynamic Interaction*	Analyzes the simultaneous spatial correlation between two individuals
V M	Location Statistics*	Generates 38 location statistics and graphical output from Point Themes
V M	Nearest Neighbor Analysis*	Conducts a Nearest Neighbor Analysis for CSR in the specified Polygon
V M	Cramer-Von Mises CSR*	Conducts a C-VM test for CSR within the specified Polygon
V M	Circular Point Statistics*	Determines the mean angle, significance, and creates a graphic histogram
V M	Harmonic Mean Point Theme*	Conducts a harmonic mean home range analysis, producing a Point Theme
V M	Spider Distance Analysis*	Conducts multiple types of distance analysis for habitat selection
V M	Compositional Analysis*	Conducts a compositional analysis of habitat selection
V M	Availability Analysis*	Conducts an availability analysis of habitat selection
V M	Classify Points by Polygons	Classifies each Point by the Polygon or Line on or within which it lies
V M	Random Selection*	Randomly selects a user-specified number of points
V M	Outlier Removal*	Removes the user-specified % of points via the harmonic mean method
V M	Generate Random Points*	Generates several types of random distributions within a Polygon
V M	Add XY Coordinates to Table	Adds X and Y coordinate Fields to the Attribute Table
V M	Calculate Successive Distances	Calculates the distance between sequential Points
V M	Calculate Distance	Calculates the distance between a Point and all objects in another Theme
V M	Summarize Attributes	Aggregates the Attribute Table based on the user-specified requests
V M	Sort Shape File	Permanently sorts the Point File
V M	Histogram	Creates a histogram based on a Theme's Legend Classification
V M	Batch Home Range Processing	Performs the selected home range analysis on multiple Point Themes
V M	Minimum Convex Polygon*	Calculates the minimum convex polygon home range
V M	Kernel*	Calculates a fixed kernel home range with multiple options

Table 2 Continued: Tools implemented in the Animal Movement Analyst Extension. Column 1 refers to whether the function is found within the View document (V) or the Table document (T). Column 2 is whether the function is presented as a Menu (M), Tool (T) or Button (B). An asterisk indicates routines with functions that can easily be called by other Avenue programs

V M	Jennrich-Turner*	Calculates a Jennrich-Turner bivariate normal home range
V M	Harmonic Mean*	Calculates a harmonic mean home range, but no area
V M	Delaunay Triangulation*	Generates a TIN between points for a distribution-free home range
V M	Dirichlet Tesselation*	Generates polygons around points for a distribution-free home range
V M	MCP Sample Size Bootstrap	Bootstrap test examining the effect of sample size on MCP home range area
V M	Site Fidelity Test*	Performs a site fidelity test with or without a constraining Graphic
V B	Recalculate area, length…	Updates area, length, and circumference in the units of the View projection
V B	Point Buffer	Creates a Buffer Shape File of the specified distance around each Point
V B	Delete Graphics	Deletes all Graphics in the View
V T	Display Coordinates	Displays the geographic and UTM coordinates at the specified location
V T	Nearest Neighbor*	Allows the user to draw a rectangular extent and conduct an NN test
V T	Random Normal Points	Allows the user to draw a circle and generate a random normal distribution
T M	Field Properties	Displays the Field properties of the selected Field in the active Table
T M	Add Record Numbers	Adds the record numbers in either the Table or Vtab order
T M	Selection to DBF	Exports the selected records to a new .dbf-formatted Table
T M	Create Cumulative Field	Creates a new Field with the cumulative total from the selected Field
T M	Histogram	Creates a histogram based on a selected Table Field

NB:Column 1 refers to whether the function is found within the View document (V) or the Table document (T). Column 2 is whether the function is presented as a Menu (M), Tool (T) or Button (B). An asterisk indicates routines with functions that can easily be called by other Avenue programs[4].

ability to incorporate other types of related information into the analysis.

Examples of wildlife analysis that can be performed with Arc View Tracking Analyst include urban encroachment, effects of habitat loss, reintroduction of species, or the effects of environmental conditions.

[4]http://www.absc.usgs.gov/glba/gistools/anim_mov_useme.pdf

1.7.1 Kernel Home Range

Kernel home range calculates a fixed kernel home range utilization distribution (Worton, 1989) as a grid coverage using either ad hoc calculation of a smoothing parameter, least squares cross validation (Silverman, 1986), or a user input for the smoothing parameter (H). The bivariate normal density kernel is used as suggested by (Worton, 1989). The least squares cross validation (LSCV) in this version takes significant processing time despite using the golden minimizing routine. Most user will find that the adhoc calculations are very close to the LSCV for exploratory analysis (for most datasets Hopt is usually between 0 .7 and 9 of Href[Ad hoc] in this implementation). The adhoc calculation is based on (Silverman, 1986) rather than (Worton, 1989) or (Seaman and Powell, 1996). The problem of discretization errors (0 length distances caused from rounding location positions giving a minimized h of zero) are handled slightly different than (Tufto, et al., 1996). Distance measures are uniform randomly placed between 0 and (href/100) when and only when the distance measurements are 0. This only adjusts the locations when necessary and allows for different projection and distance systems. The kernel is based on the non-corrected data. The program queries the user if they would like to adjust the LSCV or the Adhoc H. Worton (1994) suggests adjusting H by 0.8 for normal distributions and 0.5 for uniform. Work by (Seaman and Powell, 1996) that this is not necessary with the LSCV. It is our experience that the original Adhoc and LSCV smoothing parameters provide a less biased estimator than a user selected or Worton's corrections.

Three things are output from this routine: A grid coverage with the Utilization Distribution (probabilities), a polygon shapefile containing individual polygons for each selected probability, an associated attribute table containing probability and area fields for each set of probability polygons, and a message box displaying the area calculations of each probability, Note that the default probabilities are 50 and 95, and that the view must be zoomed out sufficiently to encompass the larger probability areas to create the polygon shapefile (95%, *etc*.)

1.7.2 Minimum Convex Polygon Home Range

Calculates a minimum convex polygon home range based on either the selected records or if none are selected the entire data set. A polygon shape file theme is created. The location point statistics menu choice will output a MCP as a graphic object if this is desired rather than a shape file if (View Graphics must be selected). If only area is desired then location point statistics with nothing selected will output MCP area. Yellow circles are locations and the checkered polygon is the MCP (see Figure 1).

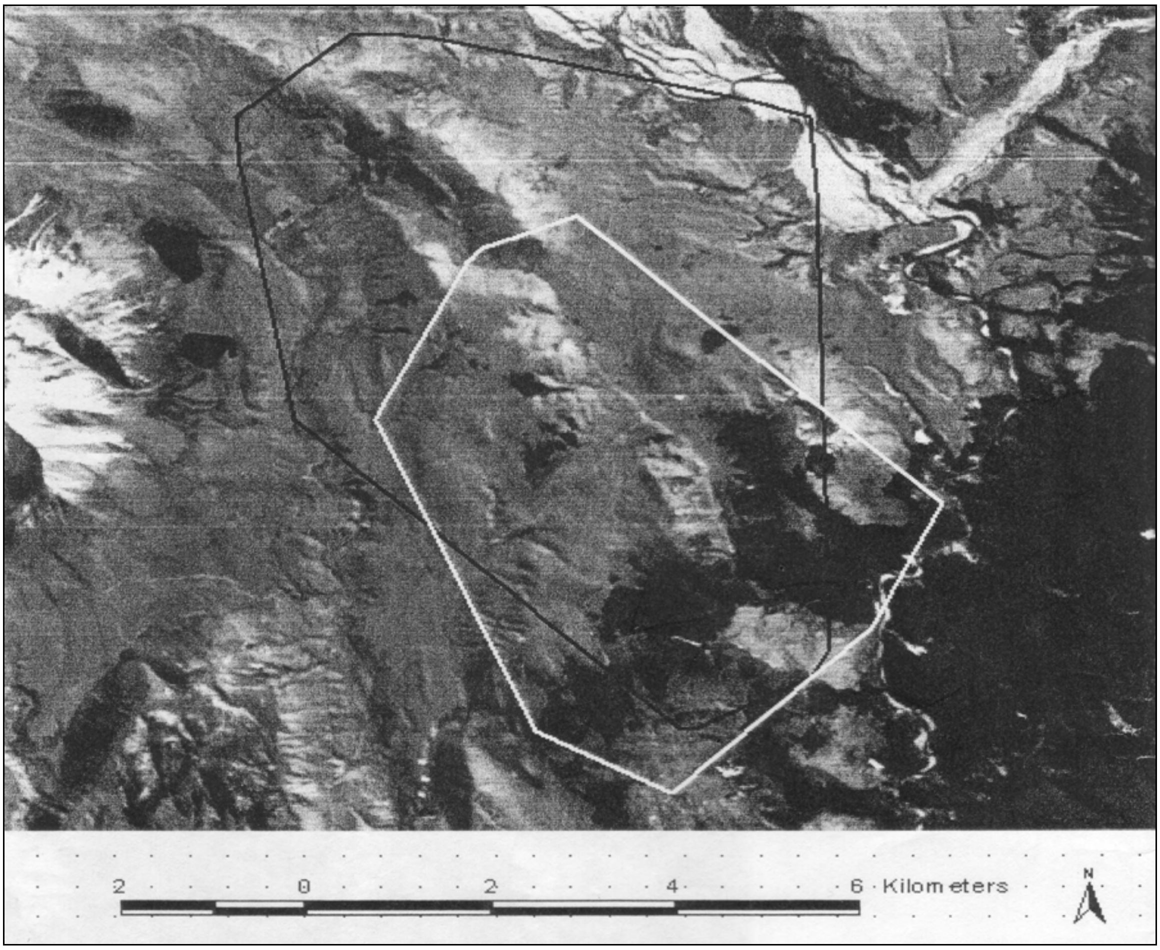


Figure 1 Minimum Convex Polygon home range analysis of stag (in black), and spiker (in white) Adapted from (M^c^Kenzie, 2004)

1.7.3 Harmonic Mean Home Range

Classify the legend using the z value. This theme can be converted to a probability grid with the cell size based on point spacing.

1.7.4 Jennrich-Turner Home Range

This implements the (Jennrich and Turner, 1969) Bivariate Normal Home Range. This method of home range calculation is seriously flawed in its dependence on a bivariate normal distribution of locations but is valuable due to its lack of sensitivity with sample size, simplicity of underlying probability theory, ability to get confidence limits on the estimates, and to derive the principle axis of the location coordinates. Other than the rare circumstances where the data is bivariately normal the main utility of this program lies in developing statistically simple home range-

Habitat models and in comparison with home range estimates using this method in other studies.

The program asks the user which probability ellipse to output (current choices are 95, 90, and 50). The program will then take the selected records (or if none are including the major and minor axis and the arithmetic mean as a graphic object. This graphic object is ungrouped so individual items can be deleted. The graphics are not erased so multiple ellipses can be generated on one or many location files. The 4ellipse can be selected and copy and pasted into polygon coverage. A message box with the arithmetic mean X and Y, the area of the ellipse, the major axis length, the minor axis length and the angle of the major axis in reference to the X axis.

1.8 Research motivation and objectives

Since the first application in 1994 of the Global Positioning System to locate wild animals (Rodgers and Anson, 1994), researchers have tested the performance and accuracy of GPS with respect to location, influence of animal activities, topographic effects, influence of sampling interval on location success rate, or the effect of equipment on animal behaviour. Few studies however, have examined the direct or interactive effects of climate on animal movement gleaned from the integration of GPS and GIS. It is noteworthy that deer movement profiles, in the Northern Hemisphere, have recently been heralded to provide formative information on global climate change (McCarthy, et al., 2001) with pole-ward and elevational movement of animal ranges, changes in animal abundance, and differential movement patterns, showing some species responding to global climate change. There is however, currently sparse knowledge regarding the inter-relatedness of movement and resource selection (and habitat use) of red deer at different scales in time and space. Proper management, conservation and contribution to mammology and ecology *per se* require that movement and resource selection (and habitat use) be accurately measured and be modelled and/or mapped to temporal factors (weather, time of day, season) and to spatial factors (forest type, topography).

This case study of two red deer (*Cervus elaphus*) seeks to investigate the movement profiles (median distance travelled) and resource selection patterns of red deer, released with no *a priori* knowledge into a heterogeneous landscape, in relation to local climate. This study also investigates the inter-relationships of movement patterns with both resource utilization and climatic change. Two temporal scales, namely daily and weekly measures of distance traveled, as well as climate and resource selection were examined. Resource selection was referenced with respect to the Land Cover Database 2 (LCDB 2[5]). The assessment of deer is based on a landscape scale, utilizes Global Positioning System (GPS), animal tracking measurements and novel statistical methods to model possible non-linear relationships and to accommodate for the time series inter-dependencies of movement with resource selection and climate. Both red deer were male and of domestic stock and released. Two seasons, namely winter and spring were analysed. Hence findings are gender and season specific and specific to naïve to habitat (domestic/released) deer. No study to date in New Zealand has tested the climatic impacts on deer movement and/or resource utilization in either naïve red deer or wild red deer *(?).*

1.9 Null Hypotheses

This current research study will test the following null hypotheses:

1. That deer movement is influenced by climate and/or dictated by particular resource selection.
2. That deer movement is geared to particular resource selection.
3. That there exists an upper and lower threshold of temperature and/or rainfall that either inhibit or encourage deer movement.
4. That there exist upper and lower thresholds of temperature and/or rainfall that are associated with either increased or decreased levels of a given resource preference.
5. Particular profiles of rainfall, temperature and distance travelled correlate with a given resource preference.
6. That there are distinct habitats within the landscape that deer utilize more frequently than others, which is significantly influenced by climate. Areas frequently occupied are likely to provide shelter and cover (from climatic impacts) and / or offer abundance of deer palatable species.
7. Differing temporal scales (daily or weekly) provide different insights into deer movement-deer resource selection and climatic profiles.
8. Differing climatic conditions correlate with increased movement for the individual deer.

[5]http://www.mfe.govt.nz/publications/ser/tech-report-61-land-jun00.pdf. A proposal for Landcover Database 2 (2000). Report by Ministry if the Environment, Wellington, NZ.

9. Distance travelled by deer interacts with rainfall and temperature with a seasonal differential in these movement and resource utilization patterns.
10. Variation will exist in habitat utilization diurnally and nocturnally.
11. Variation will exist in distance travelled diurnally and nocturnally.
12. Variation will exist in distance travelled over time with seasonal climatic changes, and the seasonal abundance and availability of desired food source.
13. Variation will exist in habitat utilization over time with seasonal climatic changes.
14. Seasonal differences in movement exist within each deer.
15. Seasonal movement profiles differ across the deer.
16. Seasonal differences in resource selection exist within each deer.
17. Seasonal resource selection profiles differ across the deer.
18. Variation exists in distance travelled with respect to time of night (within nocturnal hours).
19. Variation exists in distance travelled with respect to time of day (within diurnal hours).
20. Median distance travelled will be different for individual deer.
21. Habitat utilization will be different for individual deer.
22. One radio-marked animal's resource use is independent of all other radio-marked animals; Telemetry locations are independent in time.

1.10 Management objectives

Deer, and their management, impacts on tourism, biodiversity, human health and safety and the environment. Better management decisions are needed in New Zealand to embrace both the cultural significance of wild animals and perceived wild animal (invasion) impacts. Forest management and habitat management can and do contribute to national climate change strategies. For example in a 2005 report for climate change and UK forestry strategy (Tipper and McGhee, 2005), reduction of deer numbers is seen as strategic in facilitating better tree establishment and more rapid uptake of carbon.

In New Zealand red deer, being the most widespread and abundant deer species, are a serious management and ecological problem. It is well recognized that GPS collars increase the accuracy and transparency of scientific animal movement data, both aspects are vital to the understanding and acceptance of management practices by the NZ public. Use of GPS collar technology coupled with GIS is a current trend in overseas research for the management of wildlife and likely to become a standard wildlife research technique (D'Eon and Delparte, 2005). Managers need to continue to seek current and efficient methods to allow for timely, accurate assessment, control, and management of New Zealand's wildlife resource.

This study has the following management objectives:

1. To provide a case study of the applicability of the integration of GIS, GPS and satellite imagery technology with novel statistical methods for elucidating movement and resource utilization of large ungulate in a mixed indigenous and exotic mosaic in the Canterbury high country of New Zealand.
2. To determine how such accurate biological information (as in 1.) can be disseminated and integrated to allow for the provision of better management decisions to both cultural significance of wild animals and perceived wild animal impacts.
3. To assess the viability of GPS, GIS integrated with statistical modeling in wildlife management studies in New Zealand.
4. To add to the 2002 (Anon., 2002a) and prospective Department of Conservation (DOC) Policy Statement(s) on Deer Control, that aim to adopt an integrated approach to the control of NZ deer, working with all interest groups.

1.11 Research objectives

This study has the following broad research objectives, additional to the hypotheses stated above:

1. To provide a preliminary Canterbury high country New Zealand perspective of naïve to habitat (ex domestic) red deer response to climate.
2. To establish preliminary South Island New Zealand thresholds of temperature and rainfall for deer movement, for winter and spring.
3. To provide insight into which naïve deer individual characteristics correlate with differential distance or habitat selection.
4. To add statistical rigour to the modeling of red deer movement in relation to resource selection and climate; in addition to temporal factors such as season, time of day, and nocturnal/diurnal phases.
5. To add statistical rigour to modeling resource selection with climate *per se*.

CHAPTER 2: STUDY AREA

2.1 Location

The project site was at Craigieburn Station, Southern Alps, New Zealand. The study site is located in the Waimakariri River basin, western Canterbury, central South Island, New Zealand; and lies about 600 metres above sea level (a.s.l)(refer to Figure 2), it is surrounded by the peaks and ranges of Sugarloaf (1359 a.s.l), The Puffer (883 a.s.l), Bullock Hill (988 a.s.l), Mt Rosa (1032 a.s.l), Purple Hill (1680 a.s.l) and Mt St Bernard (1561 a.s.l). The Waimakariri River forms the station boundary to the North and East, State Highway 73 to the West and Mt St Bernard to the South. The property offers access to six lakes, notably Lakes Hawdon, Meremare, Sarah, Grasmere, Pearson and Blackwater Lake (McKenzie, 2004).

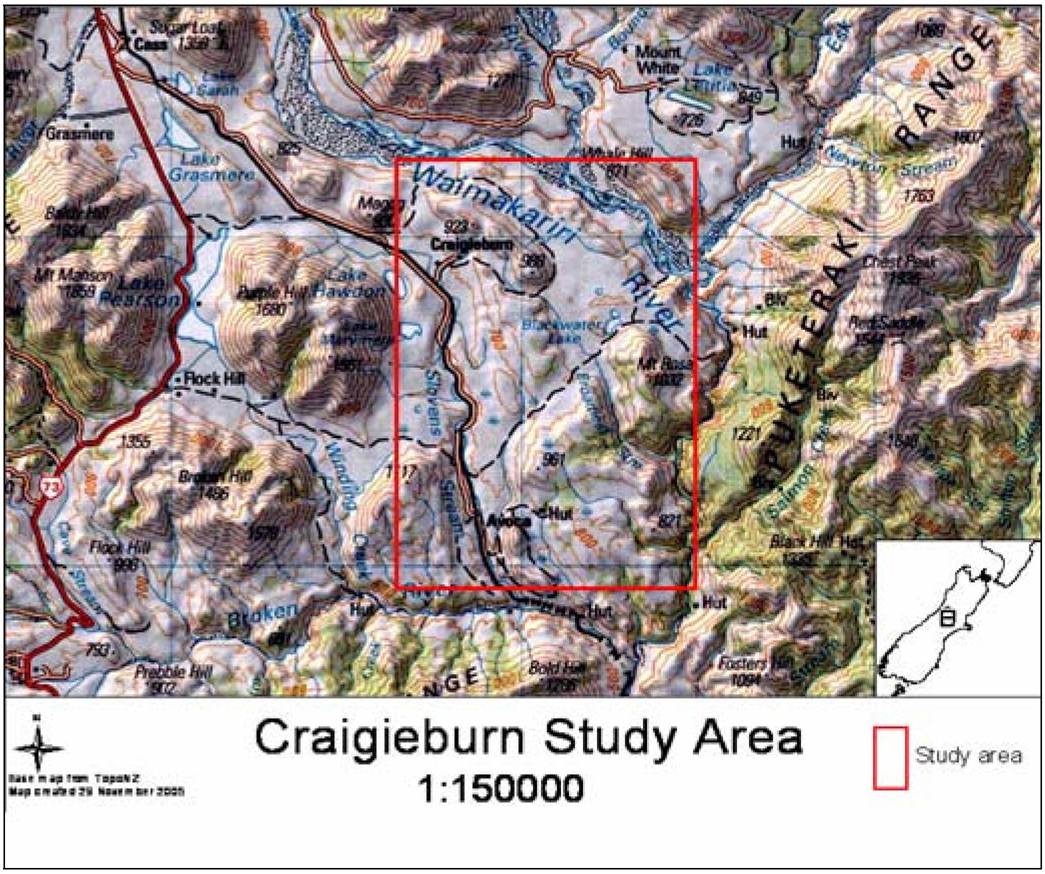


Figure 2 Location of Craigieburn in the South Island of New Zealand

2.2. Data

Data were provided from a previous study situated at Craigieburn station, Southern Alps, Canterbury, New Zealand. The data were initially analyzed at an exploratory level by McKenzie (2004) and the aim of this study was to complete further evaluation of the data. The Global Positioning System (GPS) data, the location of the animals, were collected via radio-telemetry by using Televilt GPS simplex collars fitted to red deer during the period of study from June to November in 2003. All data were converted to World Geodetic System (1984) and then transferred as dBase files to a geographical information system. These data were converted and imported into Arc View® 3.2a Geographic Information Systems (GIS) (ESRI, 1996) to calculate home range for individual deer; part of the data is dilution of precision measure so it will be possible to consider the quality of the data. In addition, animal location and calculated home range were input into GIS software (Arc View® 3.2a) relative to landscape and temporal patterns. All the location data of deer were analyzed by time series analytic spatial methods, animal movement and animal tracking analysis extension software package to develop stochastic and statistically and biologically plausible methods.

CHAPTER 3 METHODS

3.1 Introduction

This research used Global Positioning System (GPS) collars, fitted to red deer, to acquire geographic positional point data. Points were converted and imported into Arc View 3.2a Geographic Information System (GIS) to determine spatial land use. A vegetation categorization was assimilated from spectral analysis of satellite imagery within Arc View. Resource use was then determined from positional data and spatial land cover polygons to facilitate analysis. The general objective was to determine accurate resource analysis, movement and activity patterns by individual animals, and to develop concise accurate inference on resource use by red deer, as well as to field test GPS collars for use on large ungulates New Zealand (M^cKenzie, 2004).

3.2 Red Deer

Two red deer of domestic stock were purchased. The two consisted of a rising four year old red deer stag ('stag'), a rising three year old red deer stag ('spiker'). Prior to release on 9 June 2003, hard antler was removed from both stags; a process which was expected to have little behavioral influence on the deer as they were released post-rut. The stag was recovered on 22 November 2003 and the spiker on 24 November 2003 after the study period (M^cKenzie, 2004).

3.3 GPS Collar Technology

Each deer was fitted with a 'Televilt GPS Simplex store on board' GPS collar which would send weekly positional data that could be downloaded by using a Televilt RX-900 receiver. Two different weekly schedules were programmed to the collars, which were initiated to run on continuous alternate days so that day one would take 48 fixes, followed by 9 fixes on day two. This provided both fine and coarse scale positional data on alternate days. The collars' radio beaconed daily for three periods of 21 minutes and remotely transmitted weekly data sets 3 times one day a week (Wednesday), thus providing a general understanding of deer position at that time Battery life calculations anticipated a collar fix life in access of 6 months, and a recovery beacon life of between 4-6 months. The collared deer were shot to recover the GPS collars and the stored GPS locations. Collar data was then downloaded directly into a PC via Simplex Project Manager (M^cKenzie, 2004). In total 3,802 fixes were collected for red deer stag and 4, 030 fixes for red deer spiker.

3.4 Integrated Analysis

Integration of GPS fix data from the deer was then overlaid on images to determine home range analysis, movement analysis and resource selection. The distance of the deer migrated during the study was diurnally and nocturnally calculated by the animal movement extension under Arc View 3.2a, then calculated the hourly diurnal / nocturnal median distance for individual deer.

3.5 Generalized Additive Models (GAMs)

Generalized additive models (GAMs) (Hastie & Tibshirani, 1999) are a relatively recent development that extends standard linear regression to automatically fit non-linear terms, the type of which does not have to be prespecified. GAMs have been used in a number of fields such as environmental research (Axtell, et al., 2000), ecological modelling (Guisan, et al., 2002), phenological research (Hudson, et al., 2003; Hudson, et al., 2004; Hudson and Rea, 2005), political science (Beck and Jackman, 1998), biostatistics (Dalrymple, 2004; Dalrymple, et al., 2003; Hu, et al., ; Hudson, et al., ; Hudson, et al., ; Turner, et al., 2005; Veiberg, et al., 2004) and psychometrics (Turner, et al., 2005). GAMs have also been used with mixed distribution Markov models to investigate Melbourne's rainfall (Hyndman and Grunwald, 2000). Recently Hudson and Rea (2005) used an extension of GAMS (GAMLSS) (Rigby and Stasinopoulos, 2005) in a time series study of climate and sudden infant death. Earlier work by Dominici et al. (2002) used GAMs in time-series studies of air pollution in relation to health. Schwartz et al. (1996) investigated air pollution in relationship to deaths and hospital admission using the GAMs method. Croudace et al. (2002) used GAMs to study the relationship between an index of social deprivation, psychiatric admission prevalence and the incidence of psychosis.

Generalized additive models (GAMs) extend regression to a non-linear form by allowing each regression variable to have a non-linear relationship with the dependent variable. This non-linearity is calculated and tested in the process. The generalized additive model is

$$\mathbf{Y} = \beta_0 + f_1(\mathbf{X}_1) + f_2(\mathbf{X_2}) + \ldots + f_p(\mathbf{X}_p), \tag{1}$$

or

$$\mathbf{Y} = \beta_0 + \sum_{i=1}^{p} f_i(\mathbf{X}_i),$$

where f are the non-linear smoothing functions estimated in a nonparametric manner. GAMs are part of the family of mean and dispersion additive models (MADAM) developed by Rigby & Stasinopoulos (Rigby and Stasinopoulos, 1995; Rigby and Stasinopoulos, 1996a; Rigby and Stasinopoulos, 1996b) The MADAM formulation for an independently distributed response variable y_i with mean μ_i and variance $V(\mu_i, \phi_i)$, where ϕ_i is the dispersion parameter, and with probability density function $f(y_i \mid \mu_i, \phi_i)$ is as follows

$$g_1(\mu_i) = \sum_{j=1}^{p} f_j(x_{ij}),$$

$$g_2(\phi_i) = \sum_{k=1}^{q} h_k(z_{ik}).$$

the GAM is a special case of the MADAM where y is assumed to have an exponential family distribution and a constant dispersion $\phi_i = \phi$ for all i (Rigby and Stasinopoulos, 1995; Rigby and Stasinopoulos, 1996a; Rigby and Stasinopoulos, 1996b).

The smoothing functions for the GAM are found using a back fitting algorithm, details of which can be found in Hastie & Tibshirani (Hastie and Tibshirani, 1999). The back fitting, in essence, fits the smooth functions by looking at the residuals (Venables and Ripley, 1999), defined by

$$\mathbf{Y} - \sum_{p \neq j} f_p(\mathbf{X}_p), \tag{2}$$

and smoothing against the other $\mathbf{X}_j$ using cubic smoothing splines. The smoothing spline is calculated as (Hastie and Tibshirani, 1999)

$$\sum \left[y_i - f(x_i)\right]^2 + \lambda \int \left(f''(x)\right)^2 dx \tag{3}$$

for n (x_i, y_i) pairs. The smoothing spline works by fitting a series of piecewise polynomials that have break points (or knots) at the x_i's. The smoothing spline balances perfect fit against smoothness. Computation of the cubic spline starts by defining B_j spline basis functions with coefficients (γ_j) to give the smoothing function $S(x) = \sum_1^{n+2} \gamma_j B_j(x)$. Using this information and letting $\mathbf{\Omega}_{ij} = \int B_i''(x) B_j''(x) dx$ equation 3 is solved for f. Rewriting equation 3 gives

$$(y - B\gamma)^T (y - B\gamma) + \lambda \gamma^T \Omega \gamma ,$$

and

$$\frac{d}{d\gamma}((y - B\gamma)^T (y - B\gamma) + \lambda \gamma^T \Omega \gamma) = (B^T B + \lambda \Omega)\gamma - B^T y . \tag{4}$$

Setting equation 4 equal to zero and using the Cholesky factorisation $(B^T B + \lambda \Omega) = LL^T$ gives

$$LL^T \hat{\gamma} = B^T y$$

which can be solved for $\hat{\gamma}$ and thus the spline function is computed. To fit all smoothing functions the back fitting algorithm (Hastie and Tibshirani, 1999) is used. This is an iterative procedure that finds the initial estimates, and then uses the residuals, as in equation 2, to estimate the smoothing functions. The second step is repeated until there are no changes in the smoothing functions.

Not all terms in equation 1 necessarily have to have a non-linear relationship. To model both a linear and non-linear relationship the semi-parametric model is used, as follows

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + f_3(x_3) + f_4(x_4) .$$

For a given model, $\hat{\mu}$ the deviance (“Deviance” in subsequent Tables) is defined as (Hastie and Tibshirani, 1999)

$$D(y; \hat{\mu}) = 2l(\mu_{\max}; y) - l(\hat{\mu}; y)$$

where $l(;)$ is the log likelihood. This measure can be used for assessing how well the model fits because it is similar to the residual sum of squares in ordinary regression.

The deviance for the full model is compared to the model without the spline of interest, to get an approximate *F*-test for the spline (Hastie and Tibshirani, 1999). This gives a significance test for the spline function analogous to the *t*-test for a straight line.

The complexity of the non-linear GAM curve, i.e. the number of degrees of freedom associated with the smoothing spline, was selected by repeated fitting of the GAM. We fitted the model with varying dfspline for one variable (1–5) while holding dfspline of the other variables constant. We then tested the fit of the different models in an ANOVA setting (Venables and Ripley, 1999). Linearity of nested models (models including random factors) was evaluated by checking residual plots of fitted models. In case of deviation from linearity, adequate transformations (e.g. natural logarithm and arcsine) were tested. If the relationship was still non-linear, the data set was split and linear modelling was conducted on subsets.

We used a combination of direct hypothesis testing and model selection. The reason for relying on model selection was the fairly large number of parameters in some cases for which there was not always a clear prediction. When using model selection, the Akaike information criterion was used (AIC) (Akaike, 1974), which is calculated as the deviance plus twice the number of estimable parameters of a model (Burnham and Anderson, 1998). This criterion allowed us to select the most parsimonious model, i.e. the "best" balance between explained variance and degrees of freedom. We considered that two models differing in AIC value by more than 1 were significantly different (Ims and Yoccoz, 1997).

GAM modelling was performed using SAS version 9.1.3 on the Net Service Platform. The dependent variables modelled via GAMs were Euclidean

- The distance between two points (x_1, y_1) and (x_2, y_2) given by

$$MD = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)}$$

- Or LCDB2 cover type sums, calculated as summed frequency counts.

CHAPTER 4 RESULTS

4.1 Analysis of Coverage at Weekly Level

Section 4.1 provides the best-fit GAM models for the red deer stag and spiker, LCDB2 usage for coverage data analysed at a weekly level. Weekly mean levels of each of open, medium and so-called “cover” categories of LCDB2 use. Land Cover Database 2 (LCDB2) is a thematic classification of 43 land cover and land use classes covering mainland New Zealand, the near island and the Chatham Island (see Table 3 below) were modeled with respect to (1) climate; weekly average temperature (AT) and weekly rainfall (RF); (2) season (Winter and Spring); and (3) month. All two and three way interactions of these times of year and climatic predictions were tested in model building.

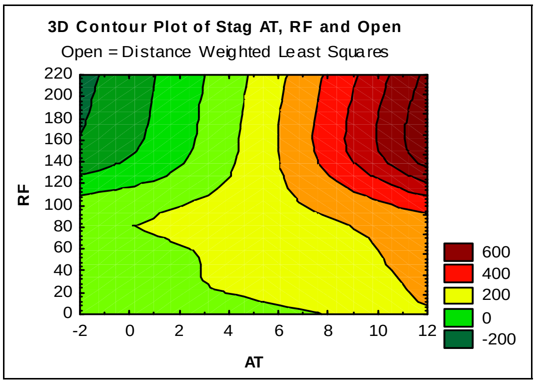


Figure 3 Stag Weekly AT, RF and Open

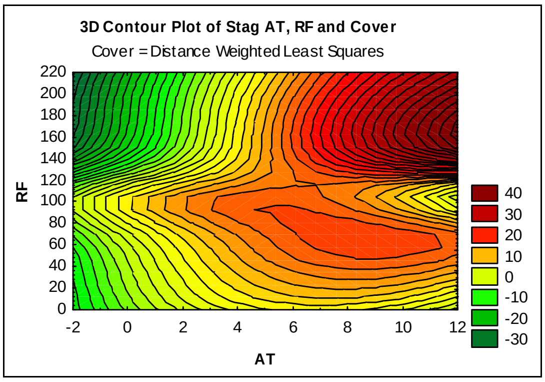


Figure 5 Stag Weekly AT, RF and Cover

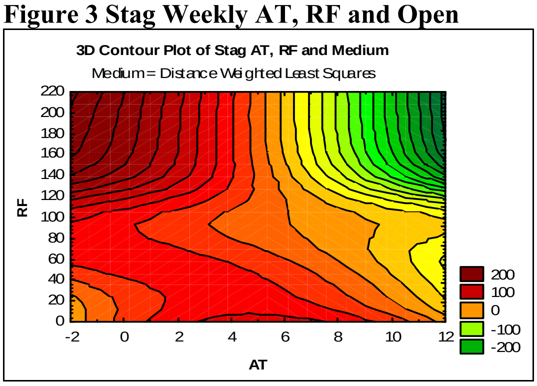


Figure 4 Stag Weekly AT, RF and Medium

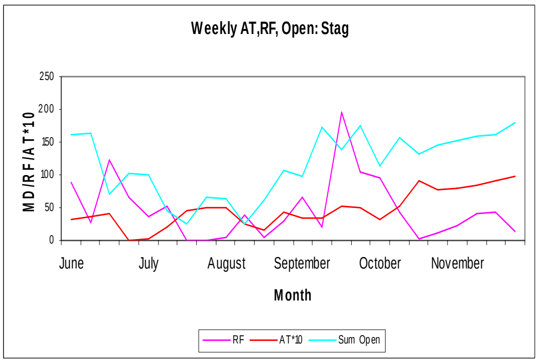


Figure 6 Stag Weekly AT, RF and Open

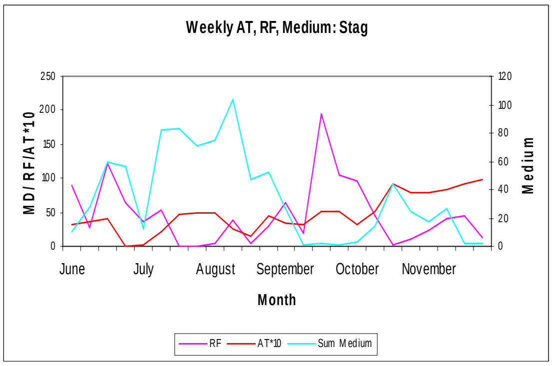


Figure 7 Stag Weekly AT, RF and Medium

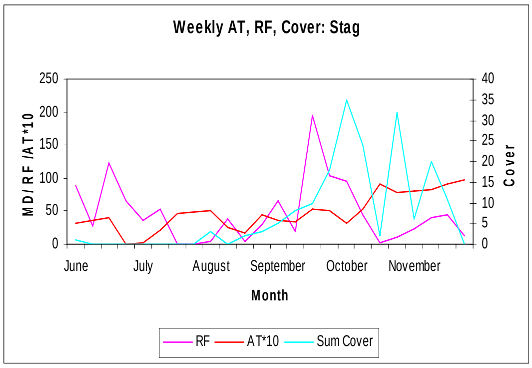


Figure 8 Stag Weekly AT, RF and Cover

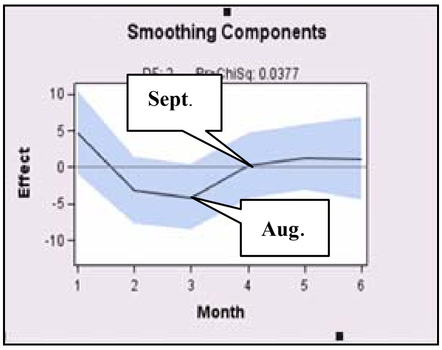


Figure 9 Stag Weekly Spline on Open Use

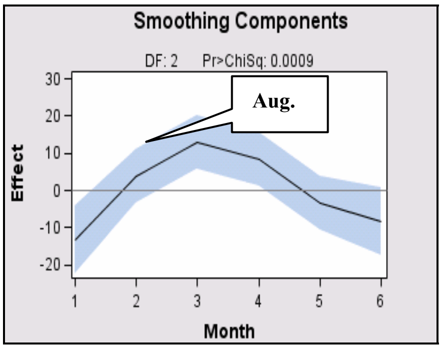


Figure 10 Stag Weekly Spline on Medium Use

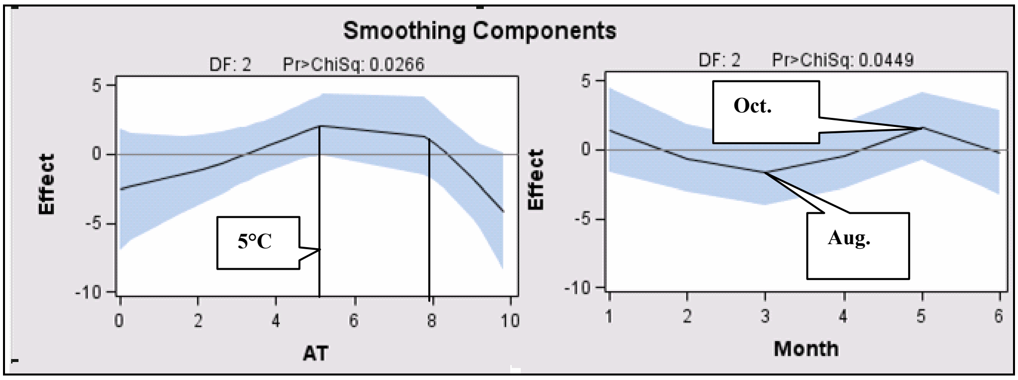


Figure 11 Stag Weekly Spline on Cover Use

Table 3 LCDB2 Use Categories for the Stag and Spiker

Spiker	Cover	Medium	Open
	Indigenous Forest	Broadleaved Indigenous Forest	Alpine gravel and Rock
		Gorse and Broom	Depleted Tussock Grassland
		Manuka and or Kanuka	Low Producing Grassland
			River and Lakeshore Gravel and Rock
			Tall Tussock Grassland
Stag	**Cover**	**Medium**	**Open**
	Deciduous Hardwoods	Broadleaved Indigenous Forest	Depleted Tussock Grassland
	Indigenous Forest	Matagouri (M)	High Producing Exotic Grassland
		Manuka and or Kanuka	Low producing Grassland
			River and lakeshore Gravel and Rock
			Tall Tussock Grassland
			Lake and pond

Table 4 Target Classes for LCDB2

1st Order Class	LCDB 1 Class	LCDB2 Class	
Artificial Surfaces	Urban Area	1	Built-up Area
	Urban Open Space	2	Urban Parkland / Open Space
	Mines and Dumps	3	Surface Mine
		4	Dump
		5	Transport Infrastructure
Bare or Lightly Vegetated Surfaces	Coastal Sand	10	Coastal Sand and Gravel
	Bare Ground	11	River and Lakeshore Gravel and Rock $_{1, 2}$
		12	Landside
		13	Alpine Gravel and Rock $_{2}$
		14	Permanent Snow and Ice
		15	Alpine Grass-/ Herbfield
Water Bodies	Inland water	20	Lake and Pond $_{1}$
		21	River
		22	Estuarine Open Water
Cropland	Primarily Horticulture	30	Short-rotation Cropland
		31	Vineyard
		32	Orchard and Other Perennial Crops
Grassland	Primarily Pastoral	40	High Producing Exotic Grassland $_{1}$
		41	Low Producing Grassland $_{1, 2}$
	Tussock Grassland	43	Tall Tussock Grassland $_{1, 2}$
		44	Depleted Grassland $_{1, 2}$
Sedgeland	Inland Wetland	45	Herbaceous Freshwater Vegetation
Saltmarsh	Coastal Wetland	46	Herbaceous Saline Vegetation
		47	Flaxland
Scrub and Shrubland	Scrub	50	Fernland
		51	Gorse and or Broom $_{2}$
		52	Manuka and or Kanuka $_{1, 2}$
		53	Matagouri $_{1}$
		54	Broadleaved Indigenous Hardwoods $_{1, 2}$
		55	Sub Alpine Shrubland
		56	Mixed Exotic Shrubland
		57	Grey Scrub
Forest	Major Shelterbelts	60	Minor Shelters
	Planted Forest	61	Major Shelterbelts
		62	Afforestation (not imaged)
		63	Afforestation (imaged, post LCDB 1)
		64	Forest – Harvested
		65	Pine Forest – Open Canopy
		66	Pine Forest – Closed Canopy
		67	Other Exotic Forest
		68	Deciduous Hardwoods $_{1}$
		69	Indigenous Forest $_{1, 2}$
		70	Mangrove

Note: Subscript $_{1}$ represents the LCDB2 stag used, $_{2}$ represents spiker used in the study.

Table 5 Stag Weekly Analysis of Landcover

Open	Variable	Estimate	Linear Effect	Spline
	Month	0.259577		0.0377
	Season	41.6370	0.0169	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	12	24.0000	2.0000
	Log Likelihood		-70.4648	
Medium	Variable	Estimate	Linear Effect	Spline
	AT	11.1717	0.0111	
	RF	1.3087	0.0211	
	Month	19.2819		0.0009
	AT*RF	-0.3134	0.0125	
	AT*Month	-3.1546	0.0208	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	12	24.0000	2.0000
	Log Likelihood		-74.4833	
Cover	Variable	Estimate	Linear Effect	Spline
	AT	-3.13188	0.0426	0.0266
	Month	3.00528	0.0002	0.0449
	AT*Month	-1.9738	0.0076	
	AT*Season	4.2763	0.0677	
	AT*RF*Month	0.0280	0.0737	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	12	24.0000	2.0000
	Log Likelihood		-59.7691	

Table 5 gives the stag's best fit coverage models. Figures 3-5 give 3D contour plots illustrating significant interactive effects of rainfall and temperature on each of the coverage use categories. Figure 6-8 are the corresponding weekly multiple time series plots of the stag's weekly summed coverage, overlaid on the 6-month weekly averages of rainfall (RF) and temperature (AT). Figures 9-11 are the corresponding spline plots for factors with a significant nonlinear effect on LCDB2 cores type use (via GAM modelling).

Table 5 shows that all the stag's coverage types are significantly affected nonlinearly (see spline effect) by month. Medium and cover use by the stag is significantly impacted also by climate, with nonlinear impacts of temperature, and interactive effects of temperature and rainfall (AT*RF, P=0.0125 for medium use; AT*RF*Month, P=0.07 for cover use). An examination of the spline plots (Figure 9-11) show that the stag's open and cover use gradually decreased in winter to a minimum in August (then maximum in October). In contrast, the stag's medium usage increased steadily over winter to a maximum in August and minimum in July and November. All LCDB2 use types show a highly significant shift with the onset of spring (Figure 9-11) (P=0.0377 (open); P=0.0009 (medium); P=0.0449 (cover)). Only medium usage decreased with the onset of spring, the stag's cover use increases with increasing temperature to about 5°C (average weekly temperature), remains stable then to 8°C, but decreases above 8°C (see Figure 10).

Table 6 Spiker Weekly Analysis of Landcover

Open	Variable	Estimate	Linear Effect	Spline Effect
	AT	-3.64472	0.0595	0.0048
	Month	8.50124	0.0079	0.0421
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	12	24.0000	2.0000
	Log Likelihood		-98.9439	
Medium	Variable	Estimate	Linear Effect	Spline
	Month	0.259577		0.0009
	AT*RF*Season	0.3199	0.1230	
	AT*RF*Month	-0.0780	0.1225	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	12	24.0000	2.0000
	Log Likelihood		-87.8988	
Cover	Variable	Estimate	Linear Effect	Spline
	AT	-6.28620	0.0692	
	Month	0.259577		0.0633
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	12	24.0000	2.0000
	Log Likelihood		-109.3106	

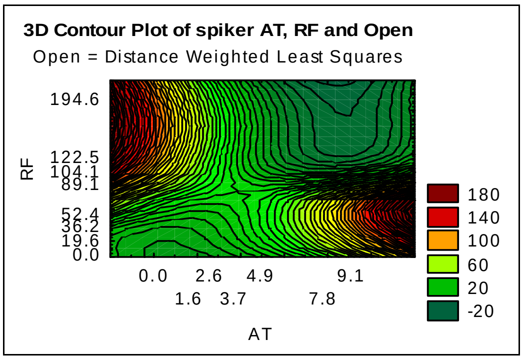


Figure 12 Spiker Weekly AT, RF and Open

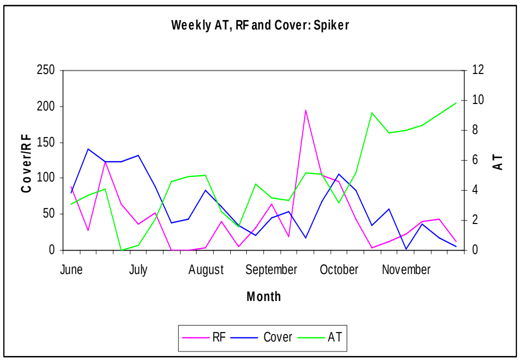


Figure 15 Spiker Weekly AT, RF and Open

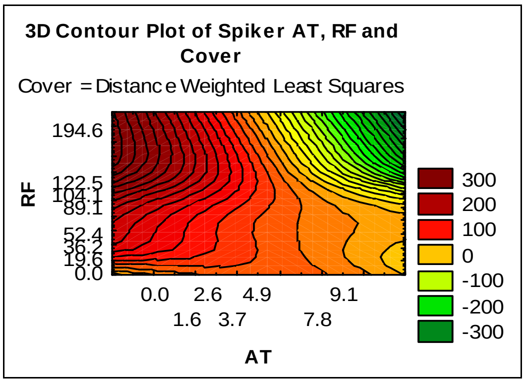


Figure 13 Spiker Weekly AT, RF and Medium

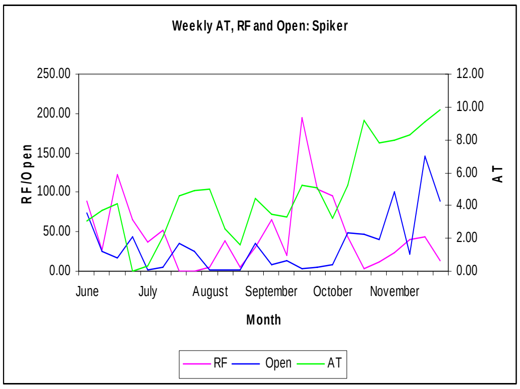


Figure 16 Spiker Weekly AT, RF and Medium

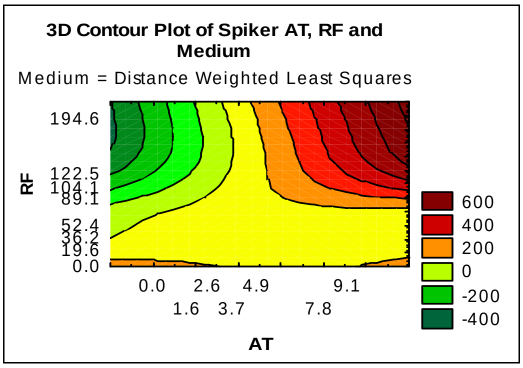


Figure 14 Spiker Weekly AT, RF and Cover

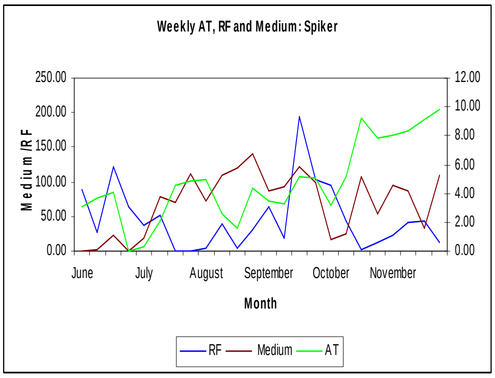


Figure 17 Spiker Weekly AT, RF and Cover

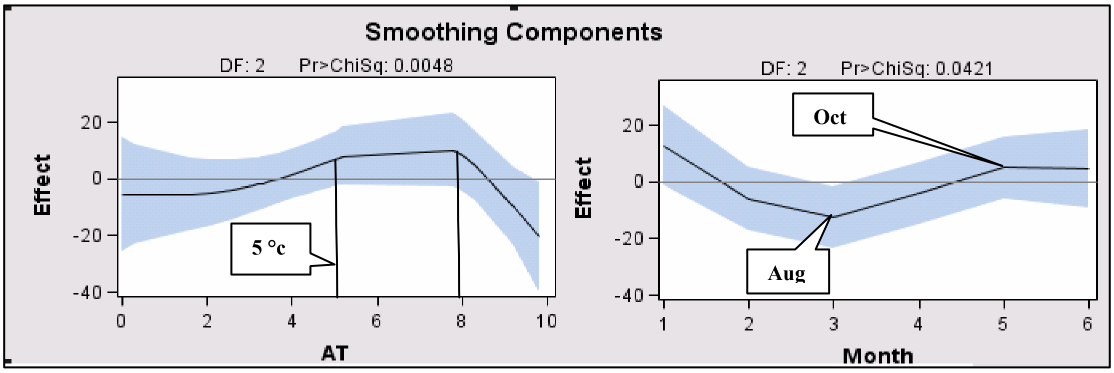
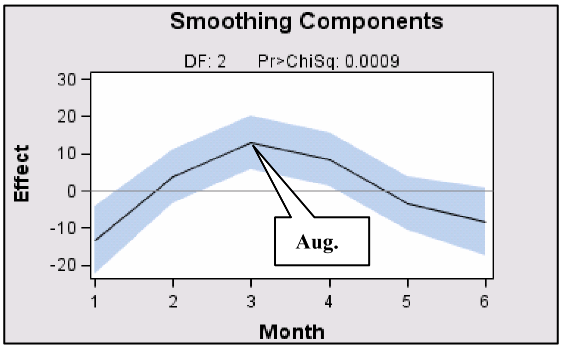


Figure 18 Spiker Weekly Spline on Open Us



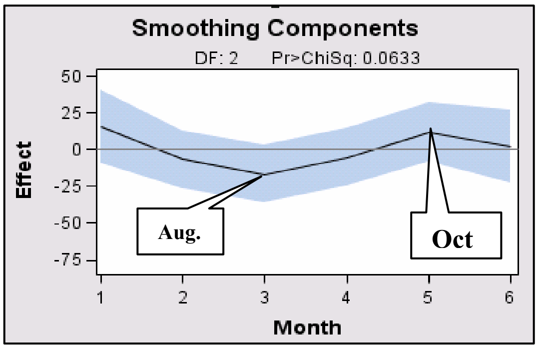


Figure 19 Spiker Weekly Spline on Medium Use

Figure 20 Spiker Weekly Spline on Cover Use

Table 6 is analogous to Table 5 giving the red deer spiker's best fit GAM models with LCDB2 cover use as dependent variables. The month of year has a significant nonlinear impact on open use (P=0.0421), medium (P=0.0009) and cover (P=0.0633, significant at 10%).

From Figure 18-20, we note that, as with the stag (Table 5), only the spiker's medium use decreases with the onset of spring (P=0.0009, Figure 19) with a maximum medium use in August by spiker, in contrast to a minimum open (P=0.042) and cover (P=0.0633) use in August, a similar trend is shown by the stag (Figure 9-11). The spiker's open use shows a nonlinear significant (P=0.0048) impact of weekly average temperature (AT) (Figure 18). Open use increases with AT to approximately 5°C, remains stable to 8°C, then decreases above 8°C (see Figure 18). This is similar to the stag's nonlinear temperature thresholds; or cover usage by the red deer stag.

4.2 Climatic Thresholds for LCDB2 Use at a Weekly Level

Table 5 and 6 showed highly significant interactive effects of weekly average temperature (AT) and rainfall (RF) on the type and level of LCDB2 cover used by the red deer stag and spiker respectively. The 3D contours (Figures 3-5 and Figures 12-14) were examined closely to obtain climatic thresholds for both AT and RF, summarized below in Table 7 and 8 for the stag and spiker respectively (see columns 3-4).

In Table 7 and 8, LCDB2 variables (open, medium, cover) are categorized into no, low, moderate or high levels (or some combination of these), Climate thresholds are also delineated for each LCDB2 category, in additional to the predominant month(s) (column 5) wherein the red deer exhibits the given LCDB2 level. (Column 6 gives the corresponding level (low=L, medium=M, or high=H) of median distance (MD) travelled by the deer to attain that given level of LCDB2 use (for the specific cover type; open, medium, or cover).

Table 7 Stag Weekly Coverage Profiles by Climate Thresholds and Conditions

LCDB2 Coverage	LCDB2 Coverage use	Temperature threshold & rainfall threshold	General climate condition	Predominant month (s)	MD levels (L/M/H)
Open	No to low open	AT<4 °C , RF<28mm, RF>125mm	Low temp. Low rainfall and high rainfall	July	L
				August	L
	Moderate to high open (100-300)	AT>4.0 °C and 108>RF>28mm	High temp. & higher rainfall	October	H
				November	H
Medium	Low medium	AT<0.8°C, RF<42mm; AT>9.3°C	Low Temp. & rainfall and high temp.	June	L
				October	H
				November	H
	Moderate to High (50-150)	0.8<AT<9.3°C and RF>42mm	Moderate temp. & moderate to high rainfall	August	L
				September	M
Cover	No cover	AT<3.5 °C, RF<80mm	Lower temp., rainfall	July	L
				August	L
	Medium Cover (10-20)	3.5<AT<10.5 °C and 80<RF<125 mm	Average rainfall & temp.	September	M
	High cover (20-40)	AT>6.6 °C and RF>125 mm	Higher temp. & very high rainfall	October	H
				November	H

Table 8 Spiker Weekly Coverage Profiles by Climate Thresholds and Conditions

LCDB2 Coverage	LCDB2 Coverage use	Temperature threshold and rainfall threshold	General climate condition	Predominant month (s)	MD levels (L/M/H)
Open	Low (<20)	AT<5.0 °C and RF<36.2mm	Low temp.& low rainfall	August	M
	Moderate (60-100)	5<AT<9.1 °C and 36.2<RF<104.1 mm	Average temp.& rainfall	July	L
				September	L
	High (>100)	AT>9.1 °C and RF>122.5mm	High temp.& high rainfall	November	H
				October	H
Medium	No medium	RF>68mm Any AT levels	High rainfall & any temp.	October	H
				November	H
	Moderate (100-200)	2.6<AT<9.6°C and 8<RF<68mm	Moderate temp. & low rainfall	July	L
				September	L
	Large (>200)	AT<2.6 °C and RF<8mm	Low temp. & rainfall	August	M
Cover	No cover (0)	AT>12.0 °C and all RF levels	High temp. & any rainfall	November	H
	medium (<100)	AT<10.3 °C and RF<13mm	High temp. & low rainfall	September	L
	High (100-200)	All AT levels and RF>28mm	Low to high rainfall & any temp.	October	H

From Table 7 it is noted that the red deer stag used a high level of "cover" in November, associated with a high level of travelling distance (MD). This is in direct contrast to the red deer spiker, who used "no cover" in that given month of November, also with associated high travelling distance. The amount of cover use for the stag is much less than the spiker for the "no cover" category (Figures 21 and 22).

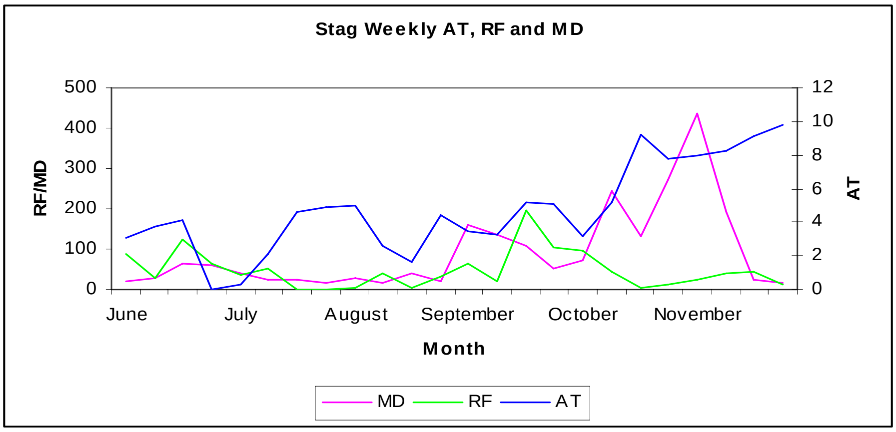


Figure 21 Stag Weekly AT, RF and MD

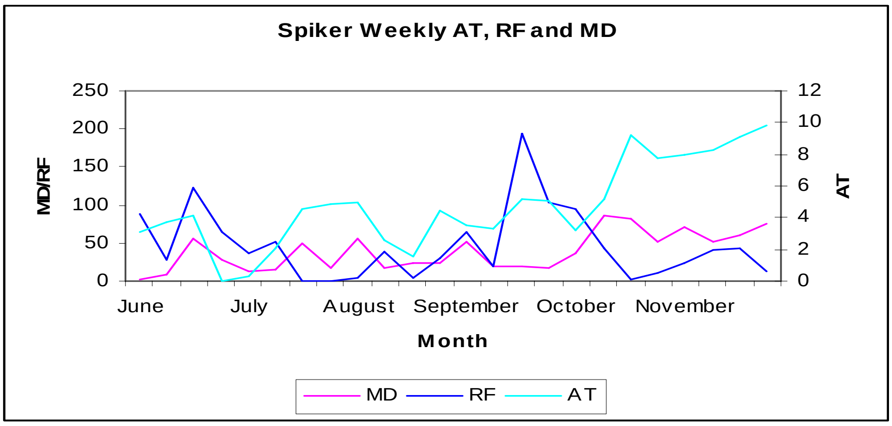


Figure 22 Spiker Weekly AT, RF and MD

High "cover" use also occurred in October for the stag and spiker, for which both deer travelled high distances (MD=H; Tables 7-8). September, the onset of spring, is associated with moderate "cover" use for the stag (with medium travelling distance) and also for the spiker (but with low travelling distance).

4.2.1 Summary

With regards to "medium" use, October and November delineate months of low medium use, for both the stag and spiker (associated with high travelling distance) (MD=H, Tables 7-8). August and September are months of moderate to high "medium" use, maximum utilization of "open" cover is in October and November for both the stag and spiker, associated also with long distance travelled for both deer (Tables 7-8). For both deer, June, July and August, for example, winter distances find to be low. Both the stag and spiker access "open" for high temperature and high rainfall and avoid "open" for low temperature and low rainfall.

In summary, Table 7 and 8 show that overall, LCDB2 cover type is season-specific, or driven also by certain climatic thresholds and often corrected with specific levels of distance that the deer travelled (MD). A rigorous statistical analysis of MD as the dependent variable in relationship to LCDB2 type (and climate) is detailed later in Section 4.6. This current Section considers LCDB2 category as the dependent and models this resource selection with respect only to climate and time of year and season (not MD).

Table 7 shows that for the red deer stag, October and November are months of high cover use and moderate to high open use. The stag utilizes little open coverage in July and August and likewise little to no “cover” in these same months. Spring’s onset in September marks the stag’s medium level use of both cover and medium LCDB2.

Table 8 shows that in contrast to the stag, the spiker uses no medium level of LCDB2 in October and November; but these months are associated with high utility of open. The spiker utilizes no cover for excessively above average temperatures exceeding 12°C (in November) in direct contrast to the stag. Cross correlational methods also show that the spiker’s use of “cover” is inversely proportional to temperature.

4.2.2 Climatic Thresholds

From Table 7 we note that for the stag , no to low utility of any LCDB2 cover whether “open”, “medium” or “cover”, is specific to winter months for low temperature and low rainfall in early July and increased rainfall in August.

Form Table 7 the respective low temperature and low rainfall winter thresholds are $AT< 4$°C and $RF<28$ mm for no to low “open”; $AT<0.8$°C and $RF<42$ mm for low “medium”; and $AT<3.5$°C and $RF<80$ mm for no “cover” use. The corresponding moderate to high utility of LCDB2 cover type, “open”, or “cover” in the late Spring months of October and November is associated with higher temperature and rainfall with respective AT and RF thresholds of (1) $AT>9.1$°C and $RF>28$ mm for “open” and (2) $AT>6.6$°C and $RF>125$ mm for “cover”. With the stag when temperatures exceed 9.3°C in October and November, there is little “medium” use. Moderate use of “medium” and “cover” are associated for the red deer stag with spring for wide temperature ranges ($0.8<AT<9.3$°C for “medium” and $3.5<AT<10.5$°C for “cover”) and with moderate to high September rainfall ($RF>42$ mm for “medium” and $80 <RF< 125$ mm for “cover”.

Table 8 can be read similarly in regard to the red deer spiker’s use of LCDB2 cover type in relation to climatic threshold and season (month).

4.3 Analysis of Distance Travelled (MD) by Climatic and LCDB 2 Coverage at a Weekly Level

In Section 4.3, the average weekly distance (MD) travelled, as measured by the Euclidean distance, is analysed with respect to 3 subcategories of models, as follows:

Model 1: Y=MD; predictors are climate, season and LCDB2;

Model 2: Y=MD; predators are climate, season and month;

Model 3: Y=MD; predictors are climate and season;

Table 9 gives the best-fit GAM models (Models 1-3, above) for the stag's distance as a dependent variable. Figures 23-25 give the stag's 3D contours associated with significant interactive effects of weekly average rainfall and temperature with respect to distance broken down by season (winter and spring).

Table 9 Stag Weekly AT, RF with Different Models

Models	Variable	Estimate	Linear Effect	Spline Effect
Stag Weekly AT, RF, Season and LCDB2 (MD as Dependent)	AT*RF	-8.1758	0.0001	
	RF*season	-17.2659	0.0001	
	AT*cover	5.1553	0.0001	
	RF*cover	2.3488	0.0001	
	RF*open	0.8877	0.0001	
	AT*RF*season	6.3158	0.0001	
	AT*RF*Medium	0.1865	0.0001	
	AT*RF*open	-0.0335	0.0001	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	7	24.0000	3.4286
	Log Likelihood		-121.2608	
Stag weekly AT, RF, Season, month (MD as Dependent)	Variable	Estimate	Linear Effect	Spline Effect
	Month	-14.8062	0.0166	
	Season	41.6370	0.0169	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	7	24.0000	3.4286
	Log Likelihood		-121.2608	
Stag weekly AT, RF, Season (MD as Dependent	Variable	Estimate	Linear Effect	Spline Effect
	AT	16.0593	0.0305	0.0124
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	16	24.0000	1.5000
	Log Likelihood		-138.3033	

Table 10 reports best-fit MD models for the spiker, for models with climate, season and LCDB2 models as before without LCDB2 but incorporating month; and the months with climate and season alone. Figures 26-28 give 3D contours of rainfall and temperature impact on the spiker's season-specific distance travelled.

Table 10 Spiker Weekly AT, RF with Different Models

Models	**Variable**	**Estimate**	**Linear Effect**	**Spline Effect**
Spiker Weekly AT, RF, Season and LCDB2 (MD as Dependent)	AT	-0.99705	<.0001	
	RF	-1.00000	<.0001	
	Medium	-0.99951	<.0001	
	Cover	-0.99977	<.0001	
	Open	4.99980	<.0001	
	Season	118.3814	<.0001	
	AT*RF	-0.4990	0.0270	
	AT*Season	-11.9472	<.0001	
	RF*Season	-1.8054	<.0001	
	AT*Cover	-0.1450	<.0001	
	RF*Cover	-0.0150	0.0023	
	AT*Medium	-0.1685	0.0485	
	AT*Open	0.6208	<.0001	
	RF*Open	0.0519	<.0001	
	AT*RF*Season	0.3173	0.0033	
	AT*RF*Cover	0.0029	0.0122	
	AT*RF*Open	-0.0072	0.0081	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	7	24.0000	3.4286
	Log Likelihood		-80.7546	
Spiker weekly AT, RF, Season, month (MD as Dependent)	Variable	Estimate	Linear Effect P value	Spline P value
	Month	49.50403	0.0029	
	AT	0.989047	0.0051	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	19	24.0000	1.2632
	Log Likelihood		-139.2804	
Spiker weekly AT, RF, Season (MD as Dependent	Variable	Estimate	Linear Effect P value	Spline P value
	AT	16.0593	0.0305	0.0124
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	20	24.0000	1.2000
	Log Likelihood		-139.2804	

The differential effects of rainfall and temperature by season for each deer are displayed by the 3D contours. However, the significant 3-way interactive effects of climate by LCDB2 (AT*RF*Medium, AT*RF*Open, AT*RF*Cover, see tables 9-10) are best interpreted via Tables 11 and 12. The latter categorize the outcome / dependent variable (MD) into low, medium, and high levels. For each deer of distance travelled, the climatic condition, temperature and rainfall conditions or thresholds are also given (Tables 11-12). Also specified, for each level of distance travelled per deer, is the predominant month and levels (low med. and high) of type of LCDB2 used (for each of "open", "medium", "cover", see column 5 of Tables 11-12).

Table 11 Stag Weekly Distance by Climate Thresholds, Conditions and Coverage Profiles

	Temperature threshold and rainfall threshold	General climate condition	Predominant month	Level of cover (Low/Med/High)
Low MD	AT<4 °C, RF<100 mm	Low temp.& low rainfall	June, July, August	Open: Low Medium: High Cover: Med
Medium MD	4<AT<6 °C, 100<RF<140 mm	Above average temp.& rainfall	September	Open: No Medium: High Cover: Med
High MD	AT> 6 °C, RF>140 mm	High temp.& high rainfall	October and November	Open: High Medium: Low Cover: High

Table 12 Spiker Weekly Distance by Climate Thresholds, Conditions and Coverage Profiles

	Temperature threshold and rainfall threshold	General climate condition	Predominant month	Level of cover (Low/Med/High)
Low MD	AT<2.6 °C, RF<63.2 mm	Low temp.& rainfall	June, July, August	Open: Low Medium: Low Cover: No
Medium MD	2.6<AT<6.2 °C, 36.2<RF<122.5 mm	Above average temp.& medium rainfall	September	Open: Med Medium: Med Cover: med
High MD	AT> 6.2 °C, RF>122.5 mm	High temp.& high rainfall	October and November	Open: High Medium: High Cover: High

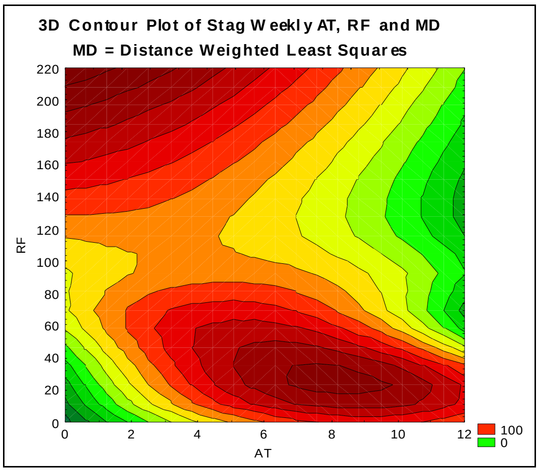


Figure 23 Stag Weekly AT, RF and MD

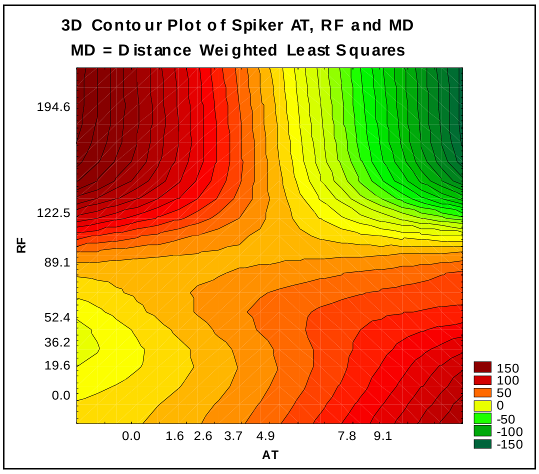


Figure 26 Spiker Weekly AT, RF and MD

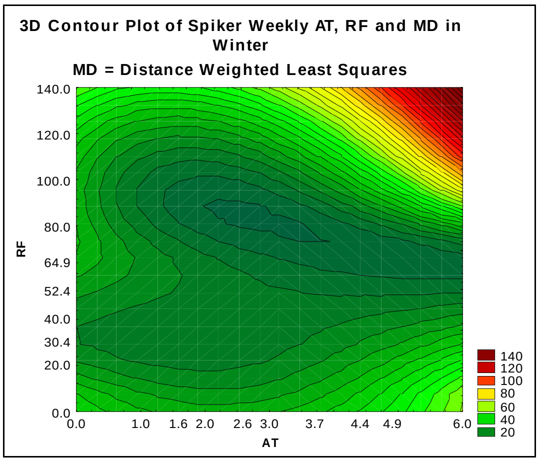


Figure 24 Stag Weekly AT, RF and MD in Winter

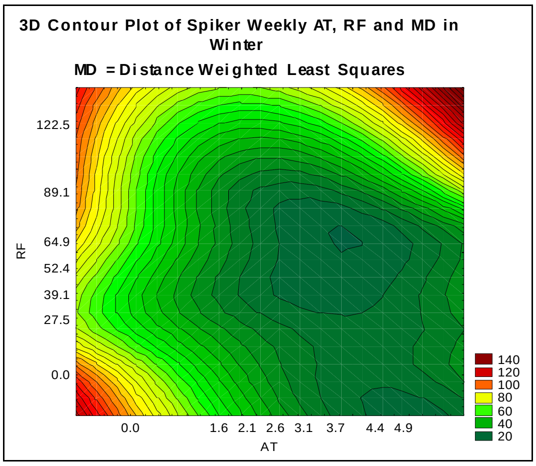


Figure 27 Spiker Weekly AT, RF and MD in Winter

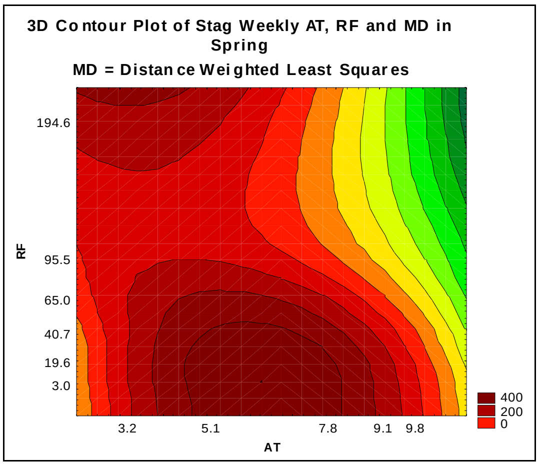


Figure 25 Stag Weekly AT, RF and MD in Spring

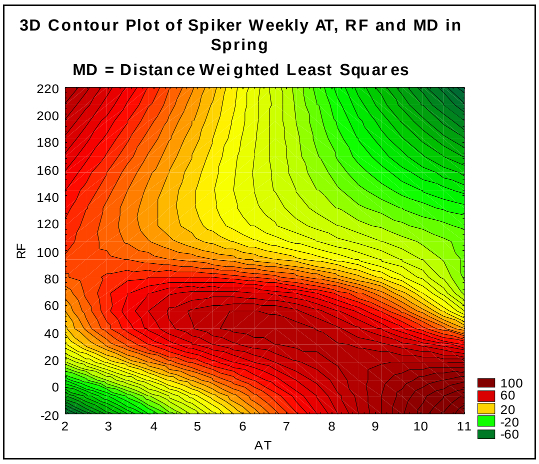


Figure 28 Spiker Weekly AT, RF and MD in Spring

Table 9 shows that there is a significant interactive impact of temperature (AT) and rainfall (RF) on the stag's weekly distance travelled (AT*RF, P=0.0001). Indeed, this interactive distance effect is significantly different between the season (AT*RF*Season, P=0.001). Furthermore, MD travelled is also significant influenced by LCDB2 coverage sought for medium use (AT*RF*Medium, P=0.0001) and "open" use (AT*RF*Open, P=0.0001). Spring delineates significantly increased MD for both the stag (Table 11) and spiker (Table 12).

Figures 23-25 indicate climate thresholds for rainfall less than 100 mm and rainfall in excess of 140 mm (see also Table 11) for the stag's MD levels in relation to climate and cover. Temperature thresholds for the stag are 4°C and 6°C (see also Figure 29).

From Table 11, the stag travelled long distances in October and November (see also Table 8) for high coverage weekly temperature in excess of 6°C, and high rainfall (greater than 140 mm). Similarly, from Table 8 the spiker also travelled long distances in the same months of October and November, with similar thresholds AT>6.2°C and RF>122.5 mm (see also Figures 28-30). However, in late spring for long MD the spiker accessed high levels of all LCDB2 types, but the stag avoided medium coverage in late spring (October and November) preferring high levels of "open" and "cover".

Both the stag and spiker travelled medium level distances (MD) in spring, for above average temperature (4<AT<6°C) for the stag; 2.6<AT<6.2°C for the spiker) and medium to high rainfall (100<RF<140 mm) for the stag; (36.2 <RF<122.5 mm) for the spiker. With the onset of spring in September the stag avoided "open", whereas the spiker went for medium levels of all three LCDB2 types.

Both the stag and spiker travelled short distances in July and August (also June for stag), this movement profile being associated with low temperature (AT<4°C for the stag; AT<2.6°C for the spiker) and low rainfall (RF<100 mm for the stag, RF<63.2 mm for the spiker).

Hence we note that during winter the spiker "avoided" cover use, whereas the stag utilised low levels of "open", as did the spiker. Medium cover was preferred by the stag in winter.

To summarise, Tables 11 and 12, report definitive average weekly thresholds and or ranges for both temperature (AT) and rainfall (RF) which may well determine (and are statistically corrected) to low medium and high levels of average weekly distance (MD) travelled by the red deer stag and spiker. For both deer long MD occurs in late spring (October and November) for elevated temperatures (above a threshold of 6°C for the stag and in excess of 6.2°C for the spiker).Increased travel also correlated with elevated rainfall, above 140 mm for the stag and in excess of slightly less rain of 122.5 mm for the spiker (in October and November). These respective temperature and rainfall levels delineate upper spring thresholds for increased deer movement. For both deer, winter movement is low and corrected with temperatures below a lower winter threshold of 4°C and 2.6°C for the stag and spiker respectively; and correspondingly for low rainfall below 100 mm and 63.2 mm for the red deer stag and spiker respectively (Tables 11 and 12).

Likewise, both deer travel medium level distance in the same month, for example (the onset of spring) for average level temperature in the range 4 to 6°C (weekly average) for the stag and in the range of 2.6 to 6.2°C for the spiker. The respective rainfall range for medium level travel is 100 to 140 mm for the stag and 36.2 to 122.5 mm for the spiker.

Cross correlation also confirms that the spiker's distance is inversely correlated with rainfall (see Section 4.8).

4.4 Time Series Profiles: Across Deer Comparisons in Distance Travelled by Climate and LCDB2 at a Weekly Level

Figures 29-32 give the raw weekly MD, open, medium and cover profiles for each deer. Also given for cross reference are the weekly average time profiles for temperature (AT) and rainfall (RF).

Figure 29 shows both the stag and spiker increased travel in June, October and November which perhaps reflects feed requirement and feed availability. But the stag is much more fast-moving and more active than the spiker overall. The months that the stag and spiker travelled least were July and August, possibly as both animals stay under the shelter to help meet their maintenance requirements by reducing consumption of energy during winter.

Figure 32 suggests the spiker used more open categories of LCDB2 in spring than in winter with rising AT and gradual reduction of RF whereas the stag utilized more medium in winter rather than in spring and rarely used cover in winter with little more used in spring. In contrast to the spiker (see Figure 32), the use of cover by the stag was much more pronounced in winter than in spring with a gradual decrease in amount of "cover" from June to August.

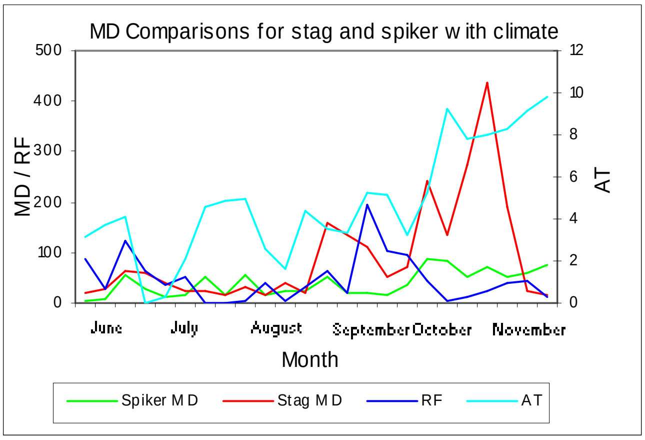


Figure 29 MD Comparison for Stag and Spiker with Climate

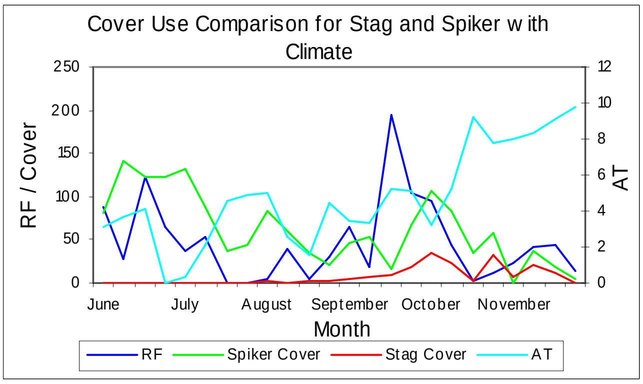


Figure 30 Cover Use Comparison for Stag and Spiker with Climate

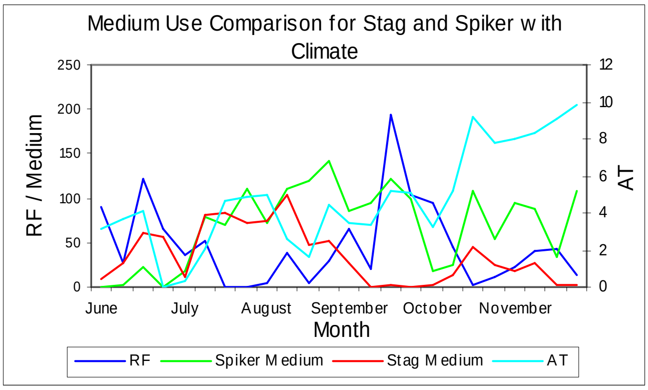


Figure 31 Medium Use Comparison for Stag and Spiker with Climate

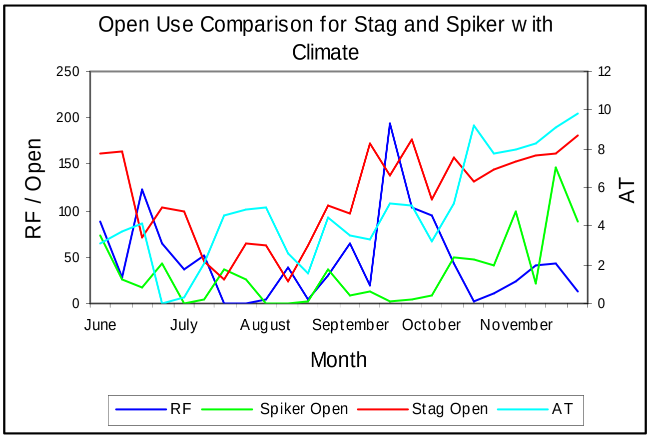


Figure 32 Open Use Comparisons for Stag and Spiker with Climate

4.5 Analysis of Coverage at a Weekly Level with Day and Night Factors

Section 4.5 reports on best-fit GAM models for the red deer stag and spiker's LCDB2 coverage in relationship to climate (AT, RF) and with respect to day and nighttime effects. All two and three-way interactions of time of day and climatic predictors were tested in the LCDB2 models. DN denotes the so-called day-night effect. Table 13 shows that the red deer stag's medium use differs significantly (P=0.05) between day and night.

Table 13 Stag Day /Night Analyses of Landcover

Open	Variable	Estimate	Linear Effect	Spline
	Month	-55.7565	0.0116	
	AT*Month	8.4572	0.0403	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Deviance	32	25482.6680	796.3334
	Log Likelihood		-218.6983	
Medium	Variable	Estimate	Linear Effect	Spline
	Intercept	36.38673	<.0001	
	RF	-0.08550	0.0964	
	Month	-6.30648	0.0032	
	AT	15.6738	0.0097	
	RF	1.6059	0.0398	
	Season	-83.5437	0.0029	
	DN	23.0848	0.0502	
	AT*RF	-0.4133	0.0165	
	AT*Month	-6.4633	0.0005	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-180.3156	
Cover	Variable	Estimate	Linear Effect	Spline
	Intercept	-2.39643	0.1529	
	Linear(Month)	1.62446	0.0054	
	DN	7.2920	0.0727	
	AT*DN	-1.7195	0.0127	
	RF*DN	-0.1455	0.0913	
	AT*RF*DN	0.0363	0.0347	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-129.1852	

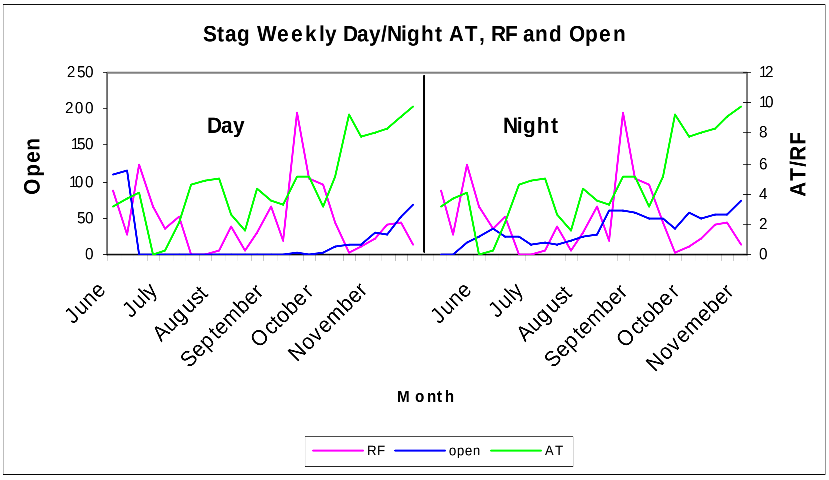


Figure 33 Stag Weekly DN, AT, RF and Open

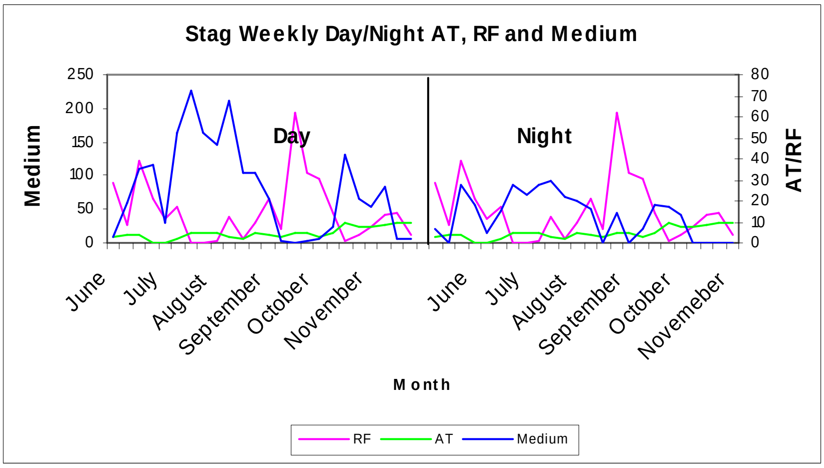


Figure 34 Stag Weekly DN, AT, RF and Medium

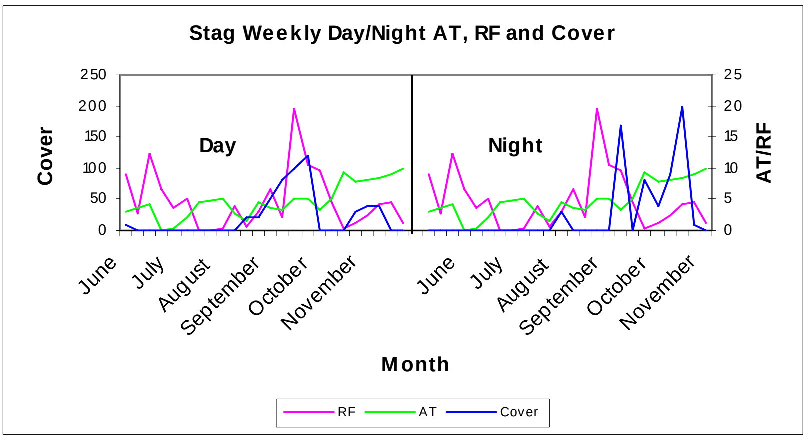


Figure 35 Stag Weekly DN, AT, RF and Cover

Figure 34 clearly reveals that daytime use of medium cover is significantly higher than night-time access to medium cover. This is in direct contrast to the red deer stag's cover use which is significantly higher during the night than daytime (Figure 35).

For the stag the interactive effect of rainfall and temperature on medium use is significant (P=0.0165), but the same across day and night. September is the month of no or low medium use with associated increased rainfall and increasing temperatures. July is the stag's month of high medium use nocturnally and diurnally (Tables 13, 14 and Figure 34). For the stag the interactive effect of rainfall and temperature on cover use differs between day and night (AT*RF*DN, P=0.0347, Table 13).

Table 14 Stag Weekly D/N Coverage Profiles by Climate Thresholds and Conditions

Time periods	LCDB2 Coverage	LCDB2 Coverage use	Temperature threshold and rainfall threshold	General climate condition	Predominant month (s)	MD levels (L/M/H)
Daytime	Open	Low(0-50)	AT<4.4 °C, RF<58mm	Low temp. & low rainfall	July	L
					August	L
					September	H
		Medium (100-150)	8>AT>4.4°C , 104.1>RF >58mm	Above average temp. & rainfall	October	M
		High (200-300)	AT>8°C, RF>104.1	High temp. & rainfall	November	H
	Medium	No (0)	All AT levels and RF>36.2mm	Any temp. & above average to high rainfall.	September	H
		Low to medium (<100)	All AT levels and RF<36.2mm	Any temp., low rainfall	June	M
					July	L
					August	L
					September	H
					October	M
	Cover	Low(<50)	AT>9.1°C and all RF levels	High temp. & any rainfall	June	M
					July	L
					August	L
					October	M
					November	H
		Medium (50-100)	AT<9.1°C, all RF levels	High to low temp., any rainfall	September	H
Night time	Open	No (0)	All AT levels, RF>104.1mm	Any temp. & high rainfall	July	L
					August	L
					September	M
		Low (0-50)	AT<7 °C, RF<7mm; 36.2<RF<104.1mm	Low temp., low rainfall & above average rainfall	October	H
		Medium (>50)	AT>7°C, all RF levels	High temp., all RF levels	June	L
					November	H
	Medium	Low(<20)	AT>10°C, 49>RF>9mm	Low rainfall, any temp.	November	H
					September	M
		Medium to high (20-60)	AT<10°C, RF<9mm; All AT levels, 104.1>RF>49mm	Low temp. & rainfall; Any temp. & medium to high rainfall	June	L
					July	L
					August	L
					October	H
	Cover	No (0)	AT<4 °C, RF<60mm	Low temp. & low rainfall	June	L
					July	L
					August	L
		Medium (10)	6.8>AT>4°C, 89.1>RF>60mm	Medium temp. & rainfall	September	M
		High(20)	AT>6.8°C, RF>89.1m	High temp. & high rainfall	October	H
					November	H

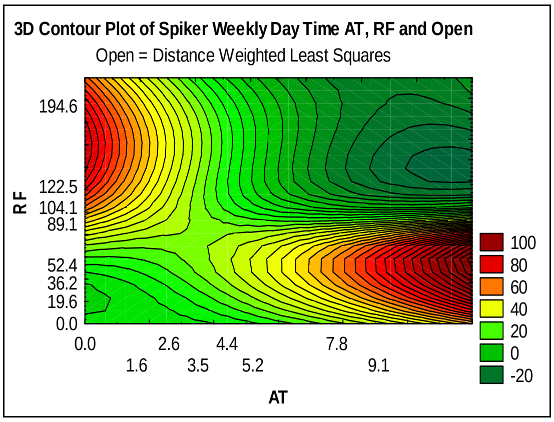


Figure 36 Spiker Weekly Daytime AT, RF and Open

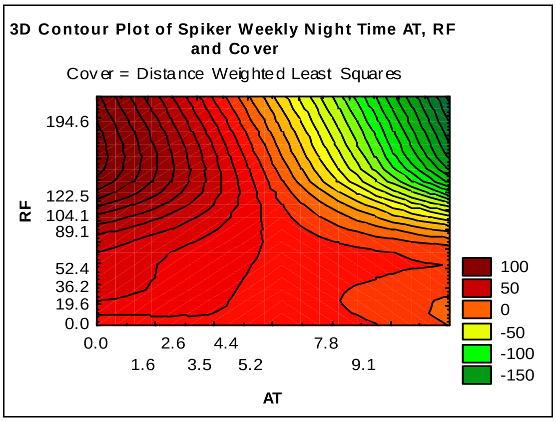


Figure 39 Spiker Weekly Night-time AT, RF and Open

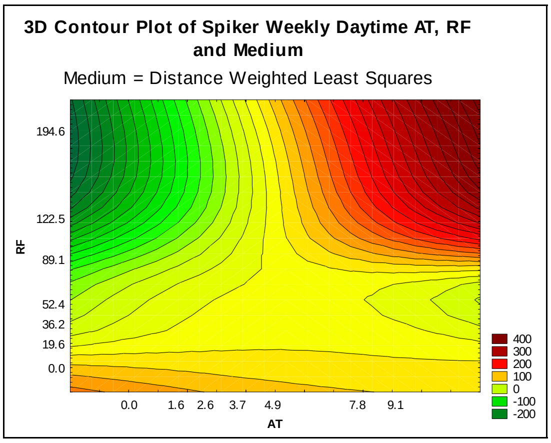


Figure 37 Spiker Weekly Daytime AT, RF and Medium

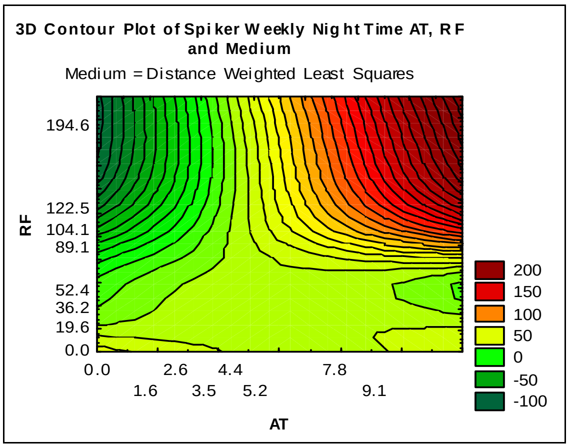


Figure 40 Spiker Weekly Night-time AT, RF and Medium

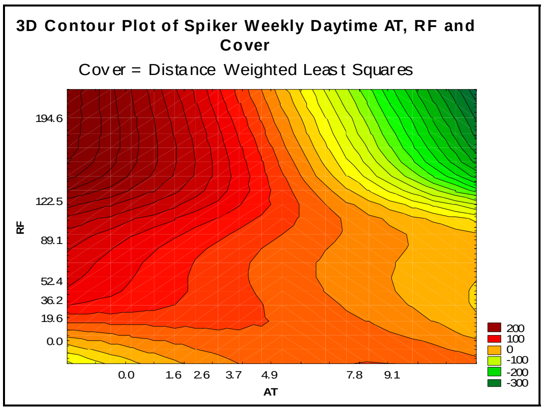


Figure 38 Spiker Weekly Day-time AT, RF and Cover

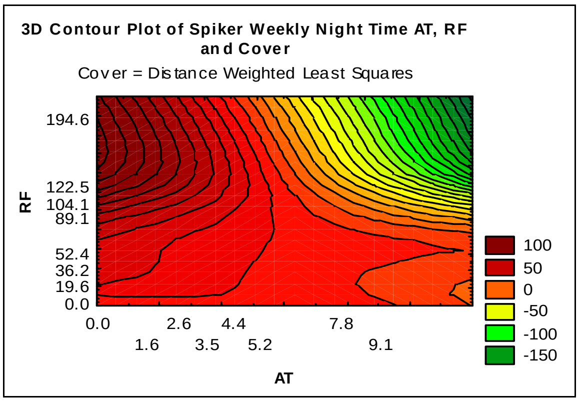


Figure 41 Spiker Weekly Night-time AT, RF and Cover

Table 14 shows for example, that in October and November, the stag's use of cover during the day is low, and associated with high temperatures. In contrast the stag's nocturnal use of cover is high in October and November (see also Figure 35). Figures 36-41 delineate the interactive effects of climate diurnally and nocturnally on the stag's use of LCDB2 overages.

Table 15 shows that the spiker's use of daytime medium cover is significantly larger or more frequent than at night (DN, P=0.0143; see also Figure 43).

Table 15 Spiker Day /Night Analyses of Landcover

	Variable	Estimate	Linear Effect	Spline
Open	Intercept	3.54360	0.5449	
	AT	2.54165	0.0500	
	Month	0.259577		0.0554
	AT*DN	3.6361	0.0798	
	AT*RF*Month	0.0636	0.1179	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-182.0418	
Medium	Variable	Estimate	Linear Effect	Spline
	Intercept	20.44303	0.0102	
	AT	2.87512	0.0871	
	Month	0.259577		0.0009
	DN	40.8108	0.0143	
	AT*RF	-0.4037	0.0975	
	AT*RF*Season	0.4997	0.0283	
	AT*RF*Month	-0.1123	0.0428	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-196.9286	
Cover	Variable	Estimate	Linear Effect	Spline
	Intercept	60.78355	<.0001	
	AT	-2.92727	0.0719	
	Month	0.259577		0.0495
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-191.4705	

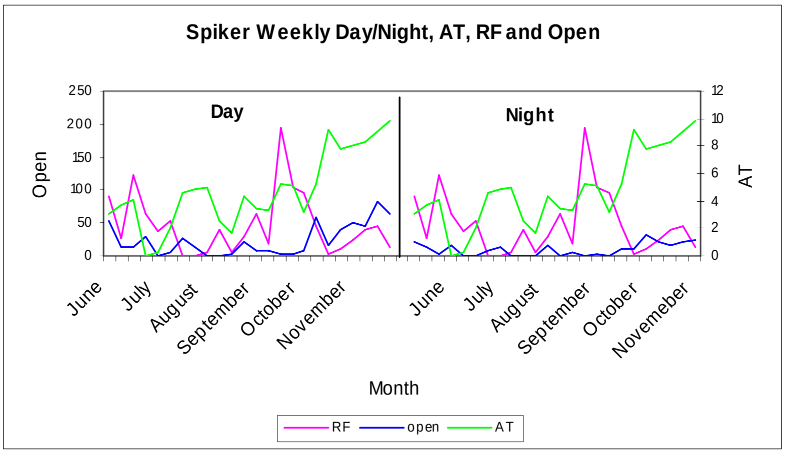


Figure 42 Spiker Weekly DN, AT, RF and Open

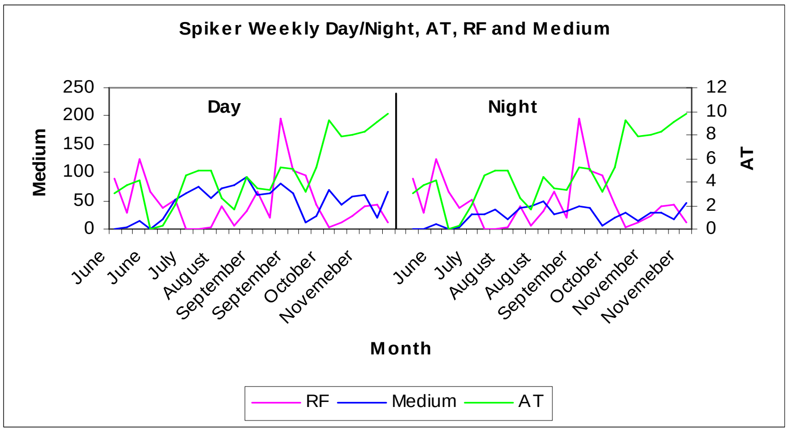


Figure 43 Spiker Weekly DN, AT, RF and Medium

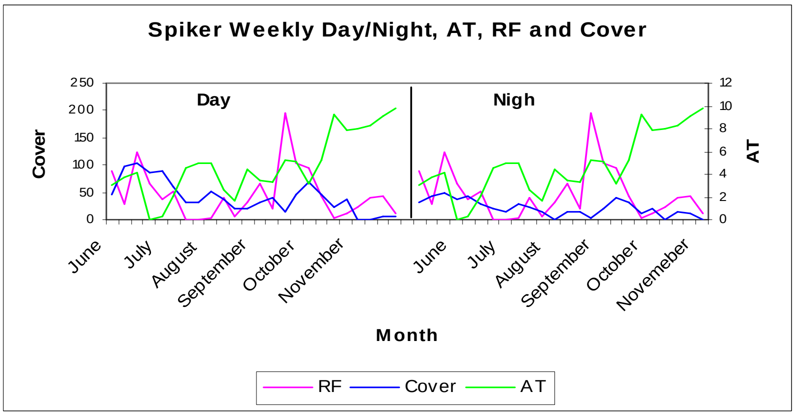


Figure 44 Spiker Weekly DN, AT, RF and Cover

The spiker's use of open increases with increased temperature more dramatically diurnally (AT*DN, P=0.07, Table 15) to a maximum in November; the spiker's use of cover is similar diurnally and nocturnal, in contrast to the stag's significantly increased access to cover during the night (Table 14). As with red deer the stag, the interactive effects of rainfall and temperature on the spiker's medium and open use is similar diurnally and nocturnally (Table 15). The spiker's use of cover overall decreased with increasing temperature (both during night and day) with June and July associated with higher cover (Table 15, Figure 44). Figures 45-47 delineate the interactive impacts of rainfall (RF) and temperature (AT) on the spiker's daytime access of respectively open, medium and cover. Figures 48-50 are nocturnal analogues of these. Thresholds reported in Table 16 are gleaned from these 3D contours (Figures 45-50).

Table 16 Spiker Weekly D/N Coverage Profiles by Climate Thresholds and Conditions

Time Periods	Landcover Categories	Landcover use	Temperature. threshold and rainfall threshold	General climate condition	Predominant month (s)	MD Levels (L/M/H)
Daytime	Open	Low to no (0-20)	AT<7.8°C, RF<70mm	Low to medium Temp. & rainfall	July	L
					August	L
					September	L
		Medium (40-60)	11.5>AT>7.8°C, 104.1>RF >70mm	Above average temp. & rainfall	October	M
		High (80-100)	AT>11.5°C, RF>104.1	High temp. & rainfall	November	H
	Medium	No (0)	All AT levels and RF>24mm	Any temp. & above average rainfall	June	M
		Medium (>100)	All AT levels and RF<24mm	Low to medium temp. & medium to high rainfall	October	M
					November	H
					July	L
	Cover	No	All AT levels and RF >44mm	Any temp. & low to high rainfall	November	H
		Low (<100)	All AT levels, 44>RF>24mm	Any temp. & above average rainfall	August	L
					September	L
					October	M
		Medium (>100)	All AT levels, RF<24mm	Any temp. & low rainfall	June	M
					July	L
Night time	Open	Low to no (0-10)	AT<5.2°C , RF<80mm	Low temp. & rainfall	July	L
					August	L
					September	L
		Medium to high (20-40)	AT>5.2°C, RF>80mm	High temp. & rainfall	November	H
	Medium	No(0)	All AT levels, RF>64mm	Any temp. & high rainfall	June	M
		Low (<50)	AT<4.2°C , RF<13mm; AT>9.5, All RF levels	Low temp. & rainfall; High temp. & any temp.	July	L
					October	H
		Medium to high (100-200)	9.5>AT>4.2°C, 64>RF>13mm	Medium to high temp. & low rainfall	August	L
					September	L
					November	H
	Cover	Low to no (<50)	AT>9.5°C,All RF levels	High temp. & any rainfall	November	H
		Medium to high (50-100)	AT<9.5°C, all RF levels	Low to medium temp. & any rainfall	June	M
					July	L
					October	H

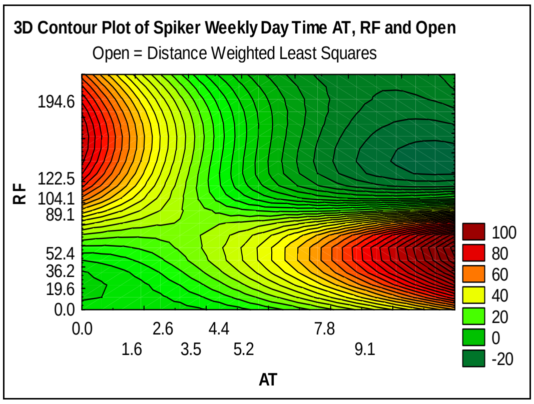


Figure 45 Spiker Weekly Daytime AT, RF and Open

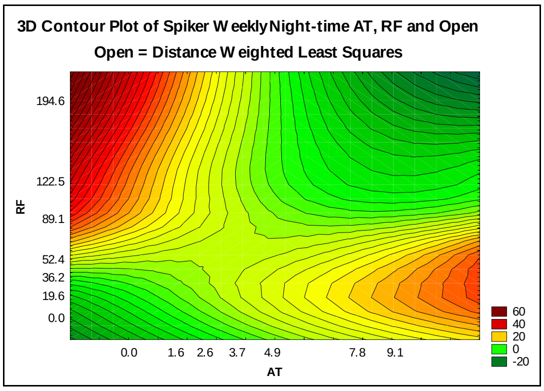


Figure 48 Spiker Weekly Night-time AT, RF and Open

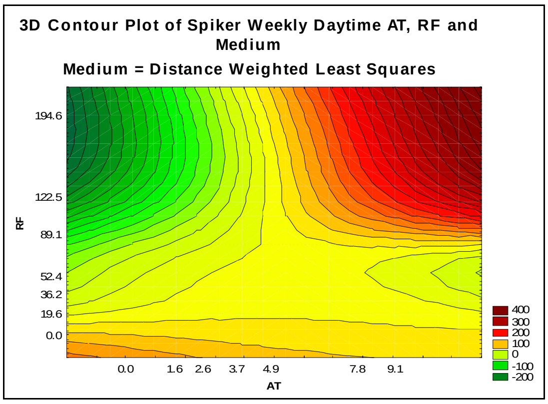


Figure 46 Spiker Weekly Daytime AT, RF and Medium

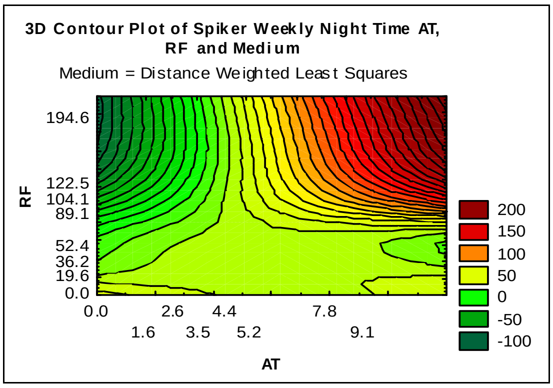


Figure 49 Spiker Weekly Night-time AT, RF and Medium

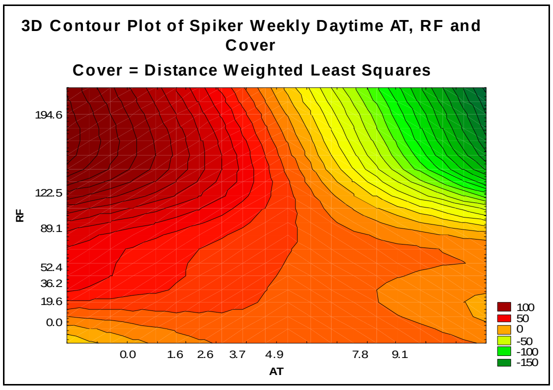


Figure 47 Spiker Weekly Daytime AT, RF and Cover

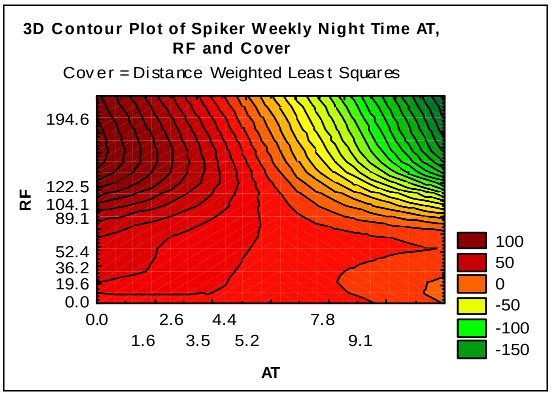


Figure 50 Spiker Weekly Night-time AT, RF and Cover

Table 14 suggests resource selection by the stag had slight differences. The stag used less open in winter and more open in October and November, but the stag used more open nocturnally in June than daytime; In contrast to medium use, the stag did not use medium diurnally in September and utilized the levels of low to medium diurnally from June to October and nocturnally in November and September, comparing with medium use of the stag, which was used more nocturnally in June, July, August and October.

In relation to cover use, the stag did not use cover nocturnally in winter, used nocturnally low level of cover in June, July, August, October and November, medium level of cover in September nocturnally and diurnally, more cover use happened in October and November nocturnally.

Table 16 shows resource utilization by the spiker had moderate difference in the study period. The spiker used less open diurnally and diurnally in July, August and September; used moderate to high open in October, November diurnally and in November nocturnally; The spiker did not use open at any time in June diurnally and nocturnally during study, but it used moderate medium in October, November and July diurnally and in August, September, and November nocturnally; For cover use, the spiker rarely used cover in November, used moderate cover in June, July and October diurnally and nocturnally.

4.6 Analysis of Weekly Distance by Day and Night, Climate, Month, Season and LCDB2

Table 17 shows that the red deer stag's distance travelled is affected by an interactive effect between temperature (AT) and rainfall (RF) which differs between winter and spring (AT*RF*Season, P=0.1092; AT*RF, P=0.008). Likewise distance travelled by the stag is also significantly influenced by climate and open resource type (AT*RF*Open, P=0.0339, Table 17); similar to the results shown earlier without testing for a day-night effect (Table 11). Temperature thresholds for open use during the day are 4.4°C and 8°C and rainfall (RF) thresholds are 58 <RF<104.1 mm.

At night the stag's corresponding thresholds for open use are 7°C and 36.2<RF<104.1 mm (Table 14).

Table 17 Stag Weekly AT, RF, with Different Models

Models	Variable	Estimate	Linear Effect P Value	Spline P Value
Stag Weekly AT, RF, Season, DN and LCDB2 (MD as Dependent)	Intercept	51.38291	0.1844	
	Month	37.58507	0.0005	
	Cover	5.56214	0.0301	
	AT	-87.7860	0.0029	
	RF	-12.3143	0.0030	
	AT*RF	2.6395	0.0080	
	AT*Month	29.5734	0.0002	
	RF*Month	-0.9619	0.0086	
	AT*Season	-39.4473	0.0582	
	RF*Season	7.6229	0.0021	
	AT*Cover	2.8410	0.0013	
	RF*Open	0.0644	0.0260	
	AT*RF*Season	-0.9264	0.1092	
	AT*RF*Cover	-0.0553	0.1087	
	AT*RF*Medium	-0.0153	0.0828	
	AT*RF*Open	-0.0205	0.0339	
	RF*Season*DN	-1.4964	0.1218	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	22	48.0000	2.1818
	Log Likelihood		-246.1548	
Stag weekly AT, RF, Season, DN and Month (MD as Dependent)	**Variable**	**Estimate**	**Linear Effect P Value**	**Spline P Value**
	Intercept	197.6522	0.1765	
	Month	0.259577		0.0485
	AT	-55.9495	0.0623	
	RF	-6.8994	0.0743	
	RF*Month	-3.0974	0.0018	
	RF*season	11.1931	0.0043	
	AT*RF*season	-1.8616	0.0196	
	AT*RF*Month	0.4245	0.0288	
	AT*RF*DN	0.5151	0.0371	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-257.0823	
Stag weekly AT, RF, Season, DN (MD as Dependent)	**Variable**	**Estimate**	**Linear Effect P Value**	**Spline P Value**
	Intercept	44.39395	0.1289	
	AT	0.989047		0.0420
	RF	0.59544	0.0014	
	AT*season	27.8628	0.0263	
	AT*RF*DN	0.5151	0.0695	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	36	48.0000	1.3333
	Log Likelihood		-263.7302	

Figure 51 and Table 17 show that day time distance travelled by the stag exceeds night time overall, particularly in spring ((AT*RF*DN, P=0.0371) and (RF*Season*DN, P=0.12)). Indeed for the stag distance is correlated positively with increased temperature both for day and night movement; but only daytime MD is positively correlated with increased rainfall. Maximum distances (MD) travelled by the stag occurs in October and November both for day and night movements.

Minimum distance travelled by the stag occurs in winter (July and August) diurnally and nocturnally.

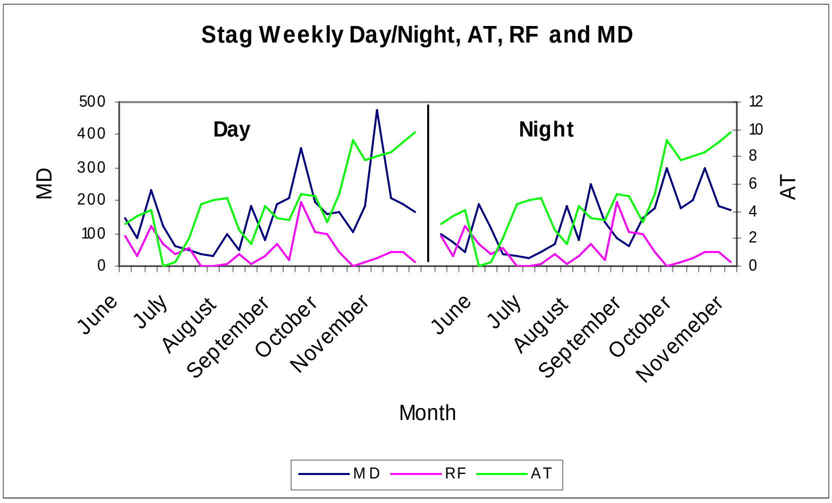


Figure 51 Stag Weekly DN, AT, RF and MD

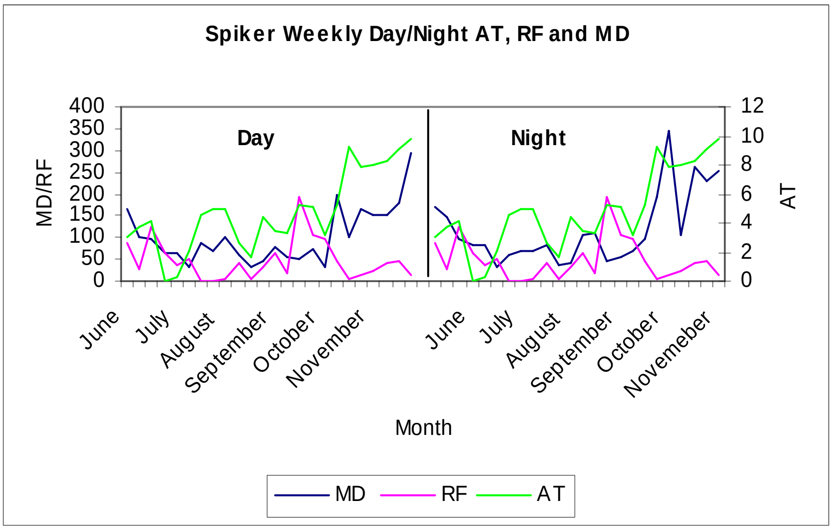


Figure 52 Spiker Weekly DN, AT, RF and MD

Table 18 shows that the spiker distance travelled is impacted by interactive effects of temperature and LCDB2 coverage (AT*Cover, P=0.0142; AT*Open, P<0.0001; AT*Medium, P=0.0316). The spiker's distance shows a positive association with average temperature which is highlighted more in spring and by day time (AT*Season*DN, P=0.0225; Table 18).

Table 18 Spiker Weekly AT, RF under Different Models

Models	Variable	Estimate	Linear Effect P value	Spline P value
Spiker Weekly AT, RF, Season , DN and LCDB2 (MD as Dependent)	Intercept	47.09731	0.0666	
	AT	18.97349	<.0001	
	Medium	-1.04690	0.0004	
	Open	0.86507	0.0308	
	Open	-3.9311	0.0719	
	AT*Season	11.5137	0.0905	
	RF*Season	-1.2570	0.0020	
	AT*Cover	1.2669	0.0142	
	AT*Medium	0.8715	0.0316	
	AT*Open	1.0412	<.0001	
	AT*DN	-40.8159	0.0957	
	AT*Season*DN	-12.8543	0.0225	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	25	48.0000	1.9200
	Log Likelihood		-224.9396	
Spiker weekly AT, RF, Season, month (MD as Dependent)	**Variable**	**Estimate**	**Linear Effect P value**	**Spline P value**
	Intercept	3.54360	0.5449	
	AT	2.54165	0.0500	
	Month	0.259577		0.0554
	AT*DN	3.6361	0.0798	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	32	48.0000	1.5000
	Log Likelihood		-182.0418	
Spiker weekly AT, RF, Season, DN (MD as Dependent	**Variable**	**Estimate**	**Linear Effect P value**	**Spline P value**
	Intercept	19.70482	0.2822	
	AT	19.63987	<.0001	
	RF	3.5536	0.0737	
	RF*Season	-2.3109	0.0682	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	34	48.0000	1.4118
	Log Likelihood		-248.5430	

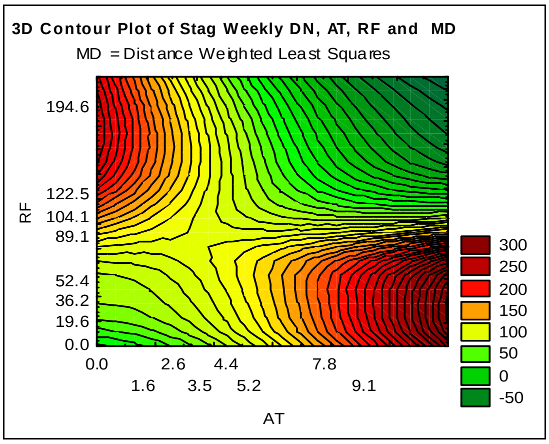


Figure 53 Stag Weekly DN, AT, RF and MD

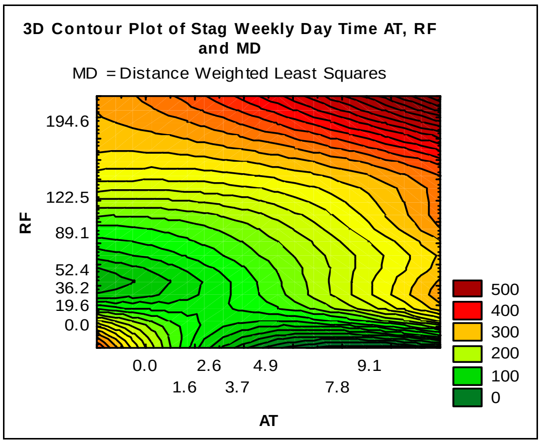


Figure 54 Stag Weekly Daytime, AT, RF and MD

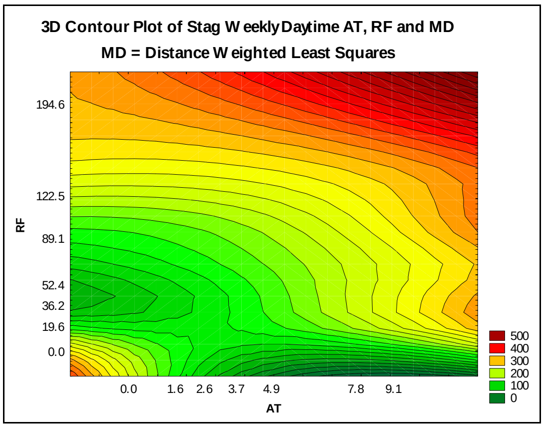


Figure 55 Stag Weekly Nighttime, AT, RF and MD

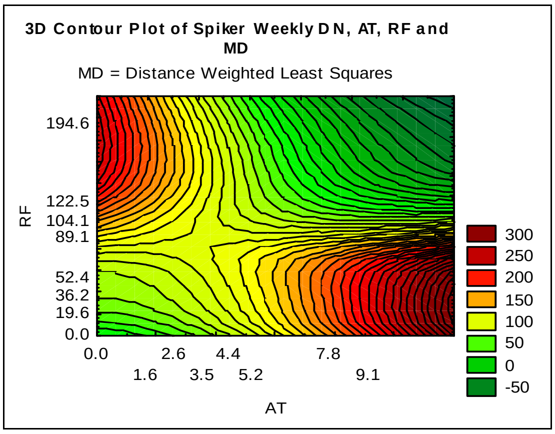


Figure 56 Spiker Weekly DN, AT, RF and MD

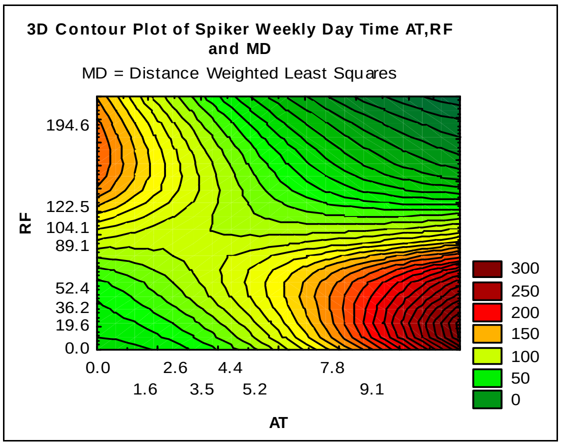


Figure 57 Spiker Weekly Daytime, AT, RF and MD

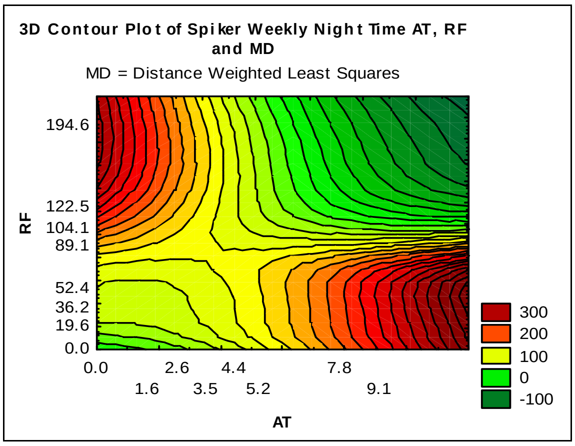


Figure 58 Spiker Weekly Nighttime, AT, RF and MD

4.7 Analysis of LCDB2 and MD: Daily Level Time Series and GAMs

Figure 59 and 60 show the red deer stag's time series plots of MD with respect to coverage daily rainfall and temperature for spring and winter respectively. Figures 63 and 64 correspond to similar plots for the red deer spiker.

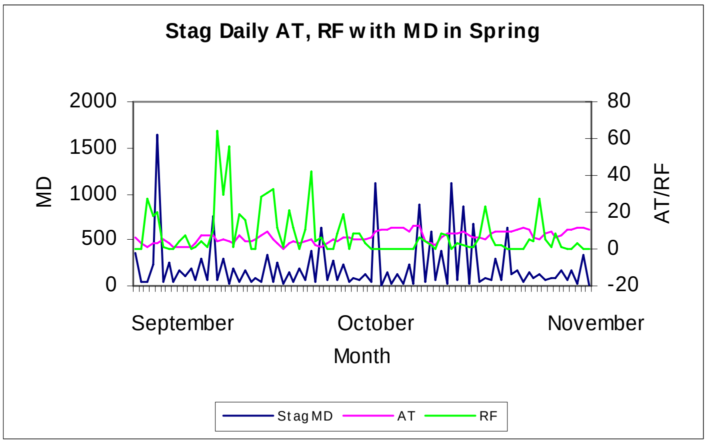


Figure 59 Stag AT, RF and MD in Spring

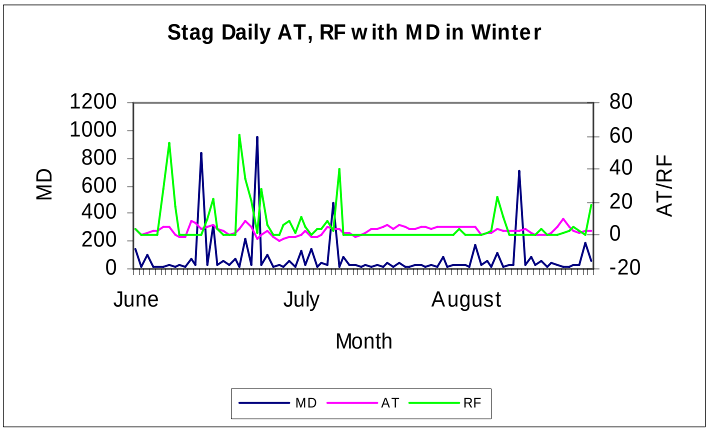


Figure 60 Stag AT, RF and MD in Winter

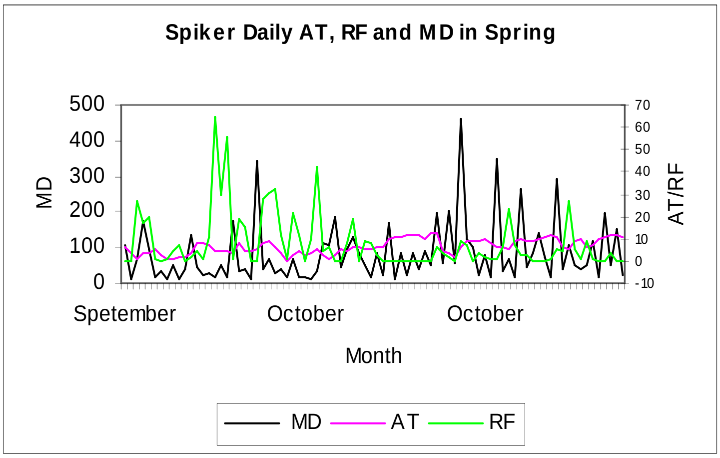


Figure 61 Spiker Daily AT, RF and MD in Spring

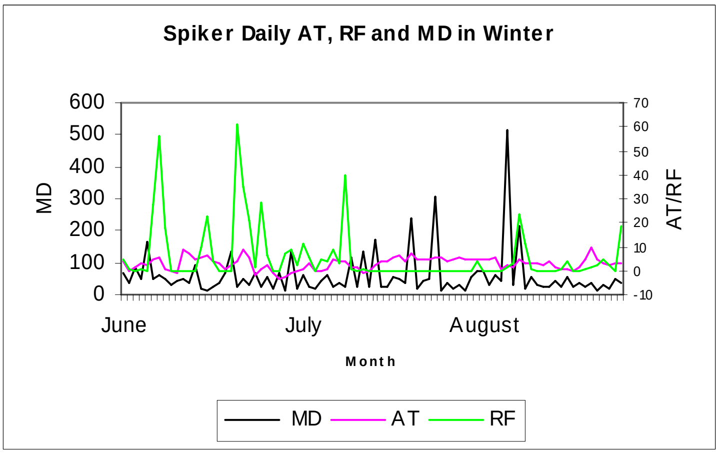


Figure 62 Spiker Daily AT, RF and MD in Winter

The above plots are based on 168 daily average readings of MD, LCDB2 coverage and climate daily average.

GAM models were also performed on the 168 daily measures broken down by day and night measures of MD, LCDB2 coverage and climate, for example a time series of N=336 points.

For the N=336 series for both daily MD, LCDB2 coverage and climate it was shown that (at a daily level) night and day distance travelled by both deer was not significantly different.

Based on the N=336 data the best-fit GAM models with MD as the dependent variable showed that the spiker's MD was non-linearly related to daily rainfall, non-linearly to open, medium and cover use (see the spline plots below).

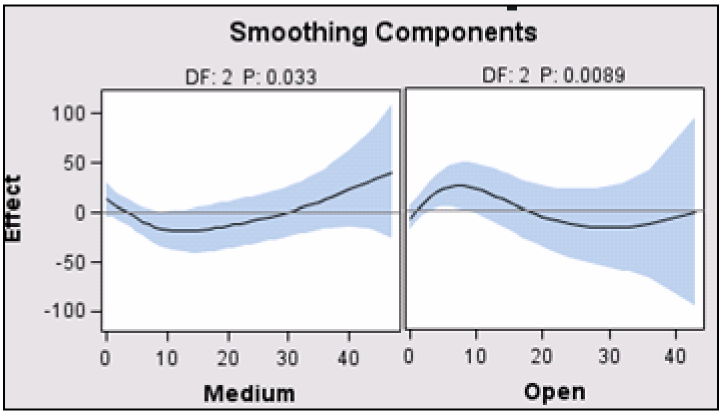


Figure 63 Spiker Daily Spline on Season, Month, Climate, LCDB2 and MD

At a daily level the red deer stag's distance (MD) was impacted on by both temperature and rainfall with the cover (AT*RF*Cover, P=0.0346). Likewise the spiker's distance travelled showed significant interactive effects between AT and RF with the open (AT*RF*Open, P=0.0006).

Table 19 Stag Daily AT, RF, Season, Landcover, Month (MD as Dependent)

AT, RF, Season, Month, and LCDB2	Variable	Estimate	Linear Effect	Spline P
	Month	18.96573	<0.0001	
	RF	0.999863		0.0001
	Cover	0.999998		0.0001
	RF*cover	-0.0245	0.0500	
	AT*RF*cover	0.0045	0.0346	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	310	336.0000	1.0839
	Log Likelihood		-1640.2890	
AT, RF, Season, DN and LCDB2	Variable	Estimate	Linear Effect	Spline P
	AT	-4.42802	0.0538	
	RF	0.999863		0.0001
	Month	9.14378	0.0233	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	320	336.0000	1.0500
	Log Likelihood		-1643.5851	

In contrast the red deer spiker's daily GAM model for Y=MD showed average daily temperature to be the biggest "drive" of distance interacting with the open utility (AT*open, P=0.0063). Likewise the effect of AT on the stag's distance travelled differed across the two seasons. Table 16 gives the best GAM models for the red deer spiker's distance (Y=MD).

Table 20 Spiker Daily AT, RF, Season, Landcover, Month (MD as Dependent)

Model	Variable	Estimate	Linear Effect	Spline P
AT, RF, Season, Month, and LCDB2	RF	2.0000		<0.0001
	Month	18.96573	<0.0001	
	Cover	2.0000		<0.0001
	RF*cover	-0.0245	0.0500	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	310	336.0000	1.0839
	Log Likelihood		-1640.2890	
AT, RF, Season, and LCDB2	Variable	Estimate	Linear Effect	Spline P
	AT	-4.42802	0.0538	
	RF	2.0000		<0.0001
	Month	27.3881	0.0256	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	320	336.0000	1.0500
	Log Likelihood		-1643.5851	
AT, RF, Season, DN, LCDB2	Variable	Estimate	Linear Effect	Spline P
	RF	0.999863		<0.0001
	Cover	0.999998		0.0539
	Medium	0.999993		0.0484
	Open	4.0590	0.0001	
	AT*Open	-0.9123	0.0063	
	RF*Open	-0.9885	0.0001	
	AT*RF*Open	0.1898	0.0006	
	Criteria for Assessing Goodness of Fit			
	Criterion	DF	Value	Value/DF
	Scaled Deviance	313	336.0000	1.0735
	Log Likelihood		-1650.5381	

Table 21 Stag Daily Coverage Profiles by Climate Thresholds and Conditions

Landcover Categories	Landcover use Levels	Temperature threshold and rainfall threshold	General climate condition	Predominant month (s)	MD levels (L/M/H)
Open	Medium(10-20)	AT<10.7°C,RF <21.1mm,	Low to high temp.& low rainfall	July	L
				August	L
	High (>30)	AT>10.7 °C, RF>21.1mm	High temp.& low to high rainfall	September	H
				October	H
				November	H
Medium	Low to no (0)	AT>9.7°C, 32.5>RF>17m	High temp.& low rainfall	September	H
	moderate (<20)	AT<9.7°C, 48> RF>32.5.0mm	Low to moderate temp.& low rainfall	October	H
				November	H
	High (>20)	RF>48, any AT levels	High rainfall & any temp.	July	L
				August	L
Cover	No(0)	AT<-2°C, any RF levels	Low temp. & any rainfall levels.	June	L
				July	L
				August	L
	Moderate (1)	7.15> AT>-2°C, all RF levels	Low to moderate temp., any rainfall levels	September	H
	High (2-3)	AT>7.15°C, any RF levels	High temp. & any rainfall levels	October	H
				November	H

Table 21 and 22 give the daily profiles of each deer's LCDB2 coverage (categorised no, low, moderate & high utility) with respect to the concomitant climatic thresholds, predominant month and associated level of distance travelled. Whilst these daily level temperature and rainfall thresholds differ in comparison to the earlier weekly level climate thresholds, the pattern of LCDB2 coverage, climate and distance profiles are similar across a daily to weekly level.

Table 22 Spiker Daily Coverage Profiles by Climate Thresholds and Conditions

Landcover Categories	Landcover use Levels	Temperature threshold and rainfall threshold	General climate condition	Predominant month (s)	MD levels (L/M/H)
Open	Low to no open (0-5)	0.7<AT<5.15 °C , 28<RF<38mm	Moderate temp., moderate to high rainfall	August	L
				September	L
	Moderate open (5-10)	-1.45<AT<0.7 °C , RF<28mm; 5.15<AT<10.65 °C; 38<RF<55.5mm	Low to High temp & low to high rainfall l	June	L
				July	M
	Large open (>15)	AT>10.65 °C, all RF levels	High temp. & any rainfall	October	H
				November	H
Medium	no (0)	All AT levels and 15.4< RF<37mm	Any temp.& low to medium rainfall	June	L
				July	M
	Medium (10)	All AT level, RF<15.4mm; 37<RF<44mm	Any temp.& low to medium rainfall	October	H
				November	H
	large medium (20-30)	All AT levels and RF>44 mm	Any temp.& high rainfall	August	L
				September	M
Cover	No (0)	AT>12.5°C, all RF levels	High temp.& any rainfall levels	November	H
				September	M
	Med. Cover (<40)	AT<12.5 and RF<27 mm	Low to high temp.& low rainfall	August	L
	High cover (60-100)	All AT levels and RF>27mm	Any temp. & high rainfall	June	L
				July	M
				October	H

4.8 Cross Correlational Methods

Cross correlation is a standard method of estimating the degree to which two series are correlated. Consider two series $x_{(i)}$ and $y_{(i)}$ where i=0, 1, 2...N-1. The cross correlation r at lag k is defined as

$$r = \frac{\sum_i [(x(i) - mx) * (y(i-k) - my)]}{\sqrt{\sum_i (x(i) - mx)^2} \sqrt{\sum_i (y(i-k) - my)^2}}$$

Where m_x and m_y are the means of the corresponding series. If the above is computed for all delays k=0, 1, 2...N-1 then it results in a cross correlation series of twice the length as the original series.

$$r(k) = \frac{\sum_i [(x(i) - mx) * (y(i-k) - my)]}{\sqrt{\sum_i (x(i) - mx)^2} \sqrt{\sum_i (y(i-k) - my)^2}}$$

For the deer weekly data N=24, and N=168 for daily data. When day and night readings are also calculated the respectively weekly and daily N are 48 and 336.

There is the issue of what to do when the index into the series is less than 0 or greater than or equal to the number of points. (i-k < 0 or i-k >= N). The most common approaches are to either ignore these points or assume the series x and y are zero for i < 0 and i >= N. In many signal processing applications the series is assumed to be circular in which case the out of range indexes are "wrapped" back within range, i.e.: x(-1) = x(N-1), x(N+5) = x(5) etc.

The range of lag k and thus the length of the cross correlation series can be less than N, for example the aim may be to test correlation at short delays only. The denominator in the expression above serves to normalize the correlation coefficients such that $-1 \le r_{(k)} \le 1$, the bounds indicating maximum correlation and 0 indicating no correlation. A high negative correlation indicates a high correlation but of the inverse of one of the series.

Cross correlational analysis only analyses pairwise lagged relationships; say between MD and climate (by day and night); say between MD and LCDB2 coverage (differentiated by night and day) and between nocturnal and diurnal LCDB2 coverage and climate. Cross correlational analysis does not distinguish a particular dependent or outcome (y) variable. This contrasts the more complex GAMs analysis where, say distance (MD) for a given deer, is modeled with respect to a given set of predictors (climate, season, resource use, month and day-night effects).

4.8.1 Cross Correlation: Weekly Level

Table 23 gives the cross correlations (r) lag -5 weeks for the red deer stag's weekly average distance (MD) in relation to climate (AT and RF) and in relation to LCDB2 use (open, medium, and cover). These cross correlations are also calculated for day and night weekly distances, climatic profiles and day-night specific LCDB2 coverage used by the red deer stag. Likewise Table 23 provides the cross correlations (r) of LCDB2 coverage with respect to rainfall and climate, overall and broken down with respect to day and night coverage. Only correlations significant at $P<0.05$ are reported in Table 23 and likewise for the red deer spiker (Table 24). Table 24 is analogous to Table 23 and reports the red deer spiker's cross correlational profiles at lag 0 (contemporaneous) to a lag of 5 weeks prior.

Table 23 Cross Correlations (r (lag k) for Stag Weekly

Variables Pairs	**Lags (Weeks)(k)**					
	0	-1	-2	-3	-4	-5
MD, AT	0.392	0.376	0.351	-	-	-
MD, RF	-	-	-	0.288	0.262	0.433
MD, Cover	0.455	0.579	0.354	0.495	0.595	0.345
MD,Medium	-0.323	-0.258	-0.263	-0.288	-0.388	-0.312
MD, Open	0.380	0.298	0.317	-	-	-
Cover, AT	0.279	0.371	0.248	-	-	-
Medium, AT	-0.299	-0.304	-0.432	-0.282	-0.272	-0.328
Open, AT	0.495	0.457	0.502	0.385	0.316	0.322
Cover,RF	-	0.253	0.362	-	-	-
Medium,RF	-0.326	-0.389	-0.252	-	-	-
Open,RF	-	0.351	-	-	-	-
Day/Night Comparisons						
Variables Pairs	**Lags (Weeks)(k)**					
MD (night), AT	0.415	0.442	0.410	0.397	0.338	-
MD (night), RF	-	-	-	-	-	-
MD(night), Cover (night)	0.547	0.403	0.488	-	-	-
MD(night), Medium (night)	-0.374	-	-	-	-	-
MD(night), Open (night)	0.422	0.360	0.315	0.261	0.465	0.493
Cover (night), AT	0.360	0.365	0.343	0.294	-	-
Medium(night), AT	-0.321	-0.345	-0.482	-0.361	-0.317	-0.332
Open (night), AT	0.555	0.451	0.382	0.259	0.210	0.224
Cover (night),RF	-	-	0.276	-0.169	0.292	0.196
Medium(night),RF	-	-0.373	-	0.179	-	-
Open (night),RF	-	0.177	-	-	-	-
MD (Day), AT	0.357	0.388	0.452	0.250	-	-
MD (Day), RF	0.418	-	-	-	-	-
MD(day), Cover(day)	0.551	0.414	0.222	-	-	0.418
MD(day), Medium(day)	-0.538	-0.346	-0.182	-0.160	-	-
MD(day), Open(day)	-	-	-	-	-0.271	-0.347
Cover (day), AT	-	-	-	-	-	-
Medium(day), AT	-0.193	-0.251	-0.420	-0.291	-0.240	-0.303
Open (day), AT	0.262	0.286	0.373	0.348	0.323	0.292
Cover (day),RF	0.465	0.273	-0.270	-0.173	-0.237	-0.162
Medium(day),RF	-0.417	-0.388	-0.256	-	0.325	0.169
Open (day),RF	-	-	-	-	-	-
Cover (day), Cover (night)	-	-	-	-	-	-
Medium (day), Medium (night)	0.770	0.485	-	-	-	-0.384
Open (day), Open (night)	-	-	0.271	0.293	0.304	0.274

Table 23 indicates that weekly distance travelled by the red deer stag is positively correlated with average temperature (AT) for both day movement (r=0.357 (lag 0)) and for night distance travelled (r=0.415 (lag 0)). Indeed increased distance is correlated with increased average weekly temperature for lags of up to 3 weeks prior. The stag's distance travelled by day is also positively correlated with rainfall (r=0.418 (lag 0)) during the same week. The stag's night distance is not significantly cross correlated with rainfall. Indeed distance travelled by the red deer stag is also highly correlated with higher "cover" use both by day (r=0.418 (lag 0)) and by night (r=0.547 (lag 0)) up to lags of 2 weeks prior. Nightly distance travelled by the stag is highly positively correlated with "open" coverage (r=0.422 (lag 0)), whereas daily MD is not significantly associated with "open" utilization. The more "medium" coverage utilised by the red deer stag, the less distance travelled at daytime (r=-0.538 (lag 0)) and also at night (r=-0.374 (lag 0)). It seems that the red deer stag seeks out open coverage at night and this may necessitate travelling longer distances. The stag also seeks out "cover" travelling increased distance both diurnally and nocturnally. This is in direct contrast to the red deer spiker for whom decreased distance is associated with "cover" use, both diurnally (r=-0.341 (lag 0); Table 24) and nocturnally (r=-0.297 (lag -1); Table 24). For the red deer spiker increased MD is highly correlated with increased "open" use at both daytime (r=0.846 (lag 0) to lag of 3 weeks prior) and by night (r=0.769 (lag 0); Table 24).

Table 24 Cross Correlations (r) (lag k) for Spiker Weekly

Variables Pairs	Lags (Weeks)					
	0	-1	-2	-3	-4	-5
MD, AT	0.693	0.466	0.318	0.251	0.243	-
MD, RF	-0.267	-	-	0.365	0.254	-
MD, Cover	-0.357	-0.416	-0.245	-	-	-
MD,Medium	0.301	-	-	-	-	-
MD, Open	0.467	0.319	-	-	-	-
Cover, AT	-0.646	-	-	-	-	-
Medium, AT	0.301	-	-	-	-	-
Open, AT	0.600	0.528	0.490	0.635	0.464	0.383
Cover,RF	-	0.428	0.438	0.275	-	-
Medium,RF	-	-0.379	-0.407	-0.308	-	-
Open,RF	-	-	-	-	-	-
Day/Night Comparisons						
Variables Pairs	**Lags (Weeks)**					
MD (night), AT	0.676	0.712	0.475	0.397	0.427	0.323
MD (night), RF	-0.247	-	-	-	0.233	0.364
MD(night), Cover (night)	-	-0.297	-	-	-	-
MD(night), Medium (night)	-	-	-	-	-	-
MD(night), Open (night)	0.769	0.491	0.444	-	-	-
Cover (night), AT	-0.574	-0.354	-0.207	-	-	-
Medium(night), AT	0.330	-	-	-	-	-
Open (night), AT	0.584	0.597	0.417	0.289	0.395	0.420
Cover (night),RF	0.198	0.378	0.480	0.297	-	-
Medium(night),RF	-	-0.277	-0.387	-0.260	-0.241	-0.219
Open (night),RF						
MD (Day), AT	0.693	0.630	0.540	0.433	0.383	0.367
MD (Day), RF	-0.213	-	-	-	-	-
MD(day), Cover(day)	-0.341	-0.352	-0.350	-	-	-
MD(day), Medium(day)	-	-	-	-	-	-
MD(day), Open(day)	0.846	0.645	0.429	0.309	-	-
Cover (day), AT	-0.655	-0.459	-0.320	-0.269	-	-
Medium(day), AT	0.279	-	-	-	-	-
Open (day), AT	0.616	0.573	0.531	0.445	0.460	0.375
Cover (day),RF	0.214	0.403	0.436	0.238	-	-
Medium(day),RF	-0.214	-0.406	-0.411	-0.269	-	-
Open (day),RF	-	-	-	-	-	-
Cover (day), Cover (night)	0.926	0.601	0.353	0.254	-	-
Medium (day), Medium (night)	0.935	0.497	0.208	0.233	-	-
Open (day), Open (night)	0.809	0.393	0.360	0.417	-	-

From Table 23 use of both “open” and “cover” by the red deer stag increases with increasing temperature at night (r=0.555, r=0.360). During the day “open” use also increases with increased temperature (r=0.262 (lag 0), to lag 5 weeks prior. By contrast "medium" LCDB2 use by the stag increases with reduced temperature, both by night (r=-0.321) and by day (r=-0.193). A similar relationship exists with rainfall, in that, "medium" use by the stag also increases with reduced rainfall, both at night (r=-0.373 (lag -1)) and by day (r=-0.417(lag 0) to lag 2 weeks prior). Whilst there is a positive correlation between the red deer stag's night and day distance (r=0.359) and stag's night and day "medium" use; use of cover and "open" differ between day and night.

Table 24 indicates that weekly distance travelled (MD) by the red deer spiker is highly positively correlated with average temperature (AT) for both day (r=0.693 (lag 0) up to lag of 5 weeks prior) and night (r=0.676 (lag 0) up to lag of 5 weeks prior). A similar positive relationship between MD and AT is shown by the stag (Table 12). In contrast to the stag, the spiker's distance travelled is negatively correlated with rainfall (RF), both in terms of day movement (r=-0.213 (lag 0)) and night movement (r=-0.247 (lag 0)). Increased distance travelled by the spiker is negatively correlated also with "cover" use both by day (r=-0.341 (lag 0)) and during the night (r=-0.297 (lag 1)). This is in direct contrast to the stag's positive relationship between distances travelled and "covers" use. The spiker's nightly and day distance travelled increases dramatically with increased "open" utilization (r=0.769 and r=0.846). For the spiker distance travelled is not significantly correlated to "medium" use, whether by day or night. This is in start contrast to the stag's movement by day and night, which decreases with increased use of "medium" cover. As with the stag, the spiker's use of "open" increases with increased temperature (r=0.600), in contrast to the stag, the spiker's use of "medium" increases with increased temperature (r=0.301), "cover" use by the spiker however decreases with increased temperature (r=-0.646) in direct contrast to the stag. Similar to the stag, the spiker's "medium" use decreases with increased rainfall (r=-0.379 (lag -1). As with the stag, the spiker's distance travelled by day is positively correlated with night time distance. Increased "open" use at night correlates with increased "open" use by day for the spiker, in contrast to the stag. Likewise, increased "cover" at night is associated with increased "cover" by day for the spiker, not so for the stag.

4.8.2 Cross Correlational Analysis: Daily Level

Table 25 shows the cross correlational analysis for the red deer stag based on the daily level time series of length N=168 time points. Table 26 is analogous to Table 25 and pertains to the red deer spiker. Daily cross correlational analysis is based on lags up to 7 days prior. Only correlations (r) which are statistically significant at $P<0.05$ are reported in Tables 25 and 26.

Table 25 Cross Correlations (r) (lag k) for Stag Daily

Variables Pairs	**Lags (days)**							
	0	-1	-2	-3	-4	-5	-6	-7
MD, AT MD, RF	0.156 -	0.168 -	0.175 -	- -	- -	- -	0.119 -	- -
MD, Cover MD,Medium MD, Open	- -0.250 -0.306	0.318 - 0.400	- -0.221 -0.305	0.268 - 0.450	- -0.222 -0.298	0.405 - 0.507	- -0.232 -0.294	0.306 - 0.455
Cover, AT Medium, AT Open, AT	0.149 -0.180 -	0.200 - 0.156	0.180 -0.151 0.130	0.166 - 0.167	0.181 -0.139 0.141	0.209 -0.141 0.207	0.191 -0.165 0.140	0.181 - 0.172
Cover,RF Medium,RF Open,RF	- - -	0.145 -0.208 -	- - -	- -0.198 -	- - -	- - -	- - -	- - -

Table 26 Cross Correlations (r) (lag k) for Spiker Daily

Variables Pairs	**Lags (days)**							
	0	-1	-2	-3	-4	-5	-6	-7
MD, AT MD, RF	- -	- -	- -	0.152 -	0.224 -	0.233 -	0.234 -	0.173 -
MD, Cover MD,Medium MD, Open	-0.208 -0.346 -	- 0.225 0.331	-0.225 -0.251 -	0.137 0.253 0.291	-0.199 -0.222 -0.178	0.135 0.242 0.236	-0.270 -0.193 -	0.149 0.257 0.223
Cover, AT Medium, AT Open, AT	-0.255 - 0.208	-0.178 0.133 0.192	-0.226 - 0.195	-0.231 - 0.321	-0.229 - 0.252	-0.139 - 0.224	-0.205 - 0.247	- 0.172 - 0.273
Cover,RF Medium,RF Open,RF	0.171 - -0.164	- - -	- - -0.132	- - -	- - -	- - -	0.184 - -	- -0.191 -

From Tables 25 and 26 we observe that distance travelled (MD) on a daily basis is positively correlated with daily average temperature (AT) for both the stag (lag 0 to -2 days) and red deer spiker (lags -3 to -7 days). Daily MD for each deer is not significantly cross-correlated with daily rainfall. For the red deer stag increased distance travelled is associated with increased "cover" use and decreased use of "medium" LCDB2 (Table 25). In contrast for the red deer spiker increased distance is associated with lower levels of "cover" use. "Open" use for both deer oscillates from negative to positive correlations on a day to day basis (Tables 25 and 26). "Cover" use is associated with increased temperature for the spiker (lag 0 to -7). This agrees with cross-correlational analysis performed on a weekly basis (Tables 25 and 26). For both deer increased use of “open” is significantly associated with elevated temperature on a daily basis (to lag -7 days). The stag’s utilization of “medium” cover decreases with both increased temperature (AT) and with increased rainfall (on a daily basis). For the spiker, “medium” use is not significantly correlated to either daily temperature or rainfall. However, the spiker’s “open” use decreases with increased rainfall (Table 25). The majority of these daily level correlations agree with the weekly level cross correlations reported earlier (Tables 23 and 24).

4.9 Friedman Test: Effect of Time of Day

Table 27 shows the median distance (MD) travelled by the red deer stag for 2 hourly day-time intervals calculated for each of the 6 months of observation. Figure 62 is a graphical schema of the data in Table 27. Friedman multiple comparisons test the stag day-time two hourly median distance of the data in Table 27 (blocked by month) showed a significant ($P<0.0001$) time of day effect of the stag’s movement with the distance travelled between 16:00-18:00 hours (4-6pm) being significantly higher than distance travelled by the stag later during the period 20:00-22:00 hours (8-10pm). No significant differences in MD between the other pairwise comparisons of two hourly intervals were found for the stag. The red deer spiker showed no significant time of day effect for MD broken down into 2 hourly intervals.

Table 27 Stag Day Time Every 2 Hour Median Distance

Stag D2	6-8hr	8-10hr	10-12hr	12-14hr	14-16hr	16-18hr	18-20hr	20-22hr
June	147.08	177.4	43.47	202.83	213.62	425.67	323.33	179.59
July	46.95	59.72	54.71	80.14	87.66	92.84	84.43	53.96
August	99.5	226.97	370.29	293.46	165.32	115.08	194.75	61.21
September	339.02	316.33	307.51	291.29	280.2	396.51	263.13	40.24
October	248.95	382.21	276.57	393.06	505.98	554.48	342.09	192.97
November	537.86	647.92	654.04	540.31	554.03	524.5	382.35	222.5

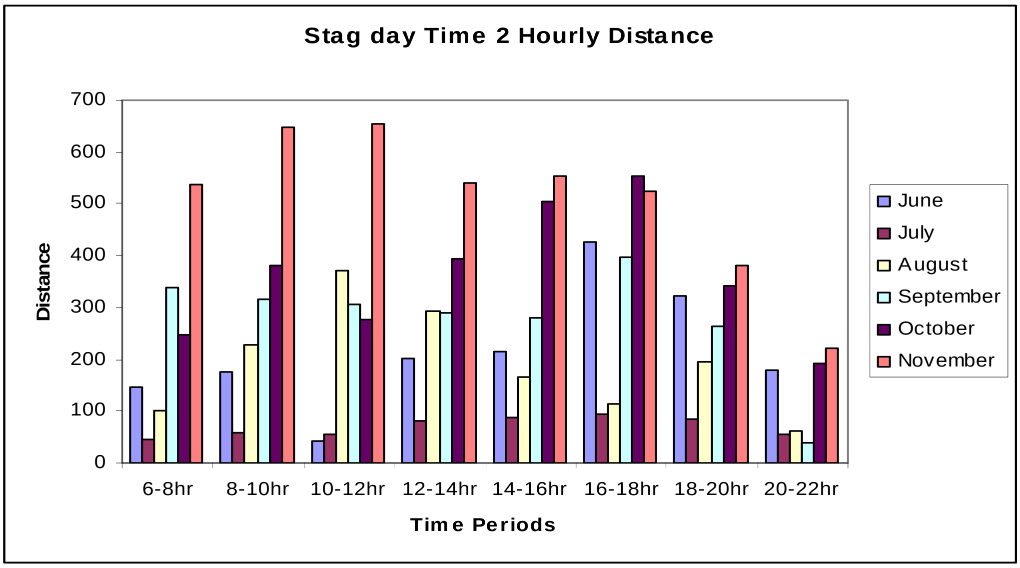


Figure 64 Stag Day Time 2 hourly Distance

However, the red deer spiker's median distance for four hourly intervals (see Table 28) namely 6:00-10:00 hour, 10:00-1400 hour, 14:00-18:00 hour and 18:00-22:00 hour. Its corresponding graphical schema (Figure 65) also shows a significantly elevated distance travelled by the spiker at 18:00-22:00 hours which is maintained for all months (Figure 65).

Table 28 Spiker Day Time Every 4 Hour Median Distance

	6-10hr	10-14hr	14-18hr	18-22hr
June	140.04	191.22	254.65	282.59
July	103.49	103.78	127.13	123.33
August	65.39	88.46	102.35	80.82
September	90.98	179.86	88.29	138.54
October	155.31	124.69	204.70	369.34
November	263.55	281.79	364.55	375.33

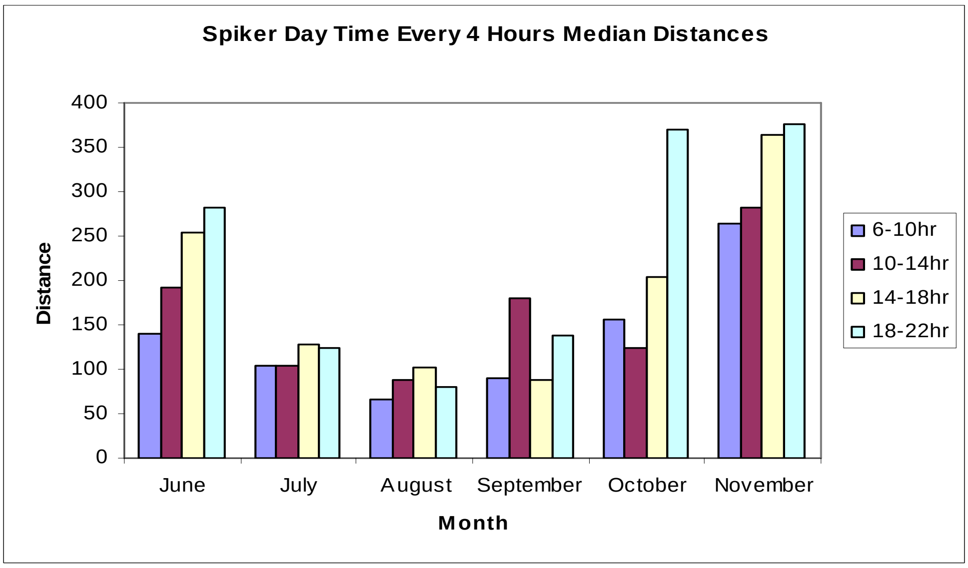


Figure 65 Spiker Day Time 4 Hourly Distance

This was confirmed statistically by a Friedman multiple comparisons test (P<0.001) for the spiker.

Tables 29 and 30 (and Figures 66 and 67) show the stag and spiker's 2 hourly night time median distance (MD) by month profiles. Night time periods of 2 hourly calculated were 22:00-24:00 hours, 00:00-2:00 hours, 2:00-4:00 hours and 4:00-6:00 hours. Friedman tests showed that for night time travel there was no statistically significant difference across the four, two hourly night- time periods of travel.

Figures 64-66 do show significant winter-deer differences between day and night-time distance travelled. Note, however the more complex GAMs models using day and night weekly MD in relation to coverage and climate did show a significant day and night difference in LCDB2 use and distance travelled by the deer.

Table 29 Stag Night Time Every 2 Hourly Distance

	22-24hr	0-2hr	2-4hr	4-6hr
June	150.37	71.06	85.18	119.27
July	65.06	76.2	109.19	44.28
August	99.8	76.01	75.96	56.75
September	81.74	68.46	117.88	98.12
October	361.61	181.35	209.35	262.05
November	257.96	226.29	243.32	407.78

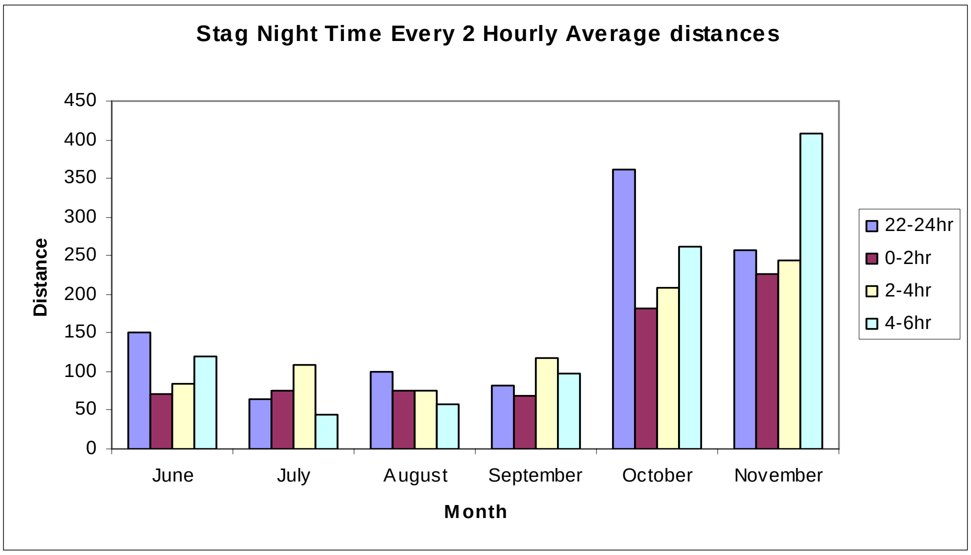


Figure 66 Stag Night Time Every 2 Hourly Distance

Table 30 Spiker Night Time Every 2 Hourly Distance

	22-24hr	24-2hr	2-4hr	4-6hr
June	260.34	213.34	24.42	38.9
July	161.82	144.93	31.1	39.19
August	95.24	92.19	26.91	18.44
September	174.63	142.19	20.92	21.05
October	284.66	231.34	54.41	27.9
November	495.25	302.94	35.17	61.2

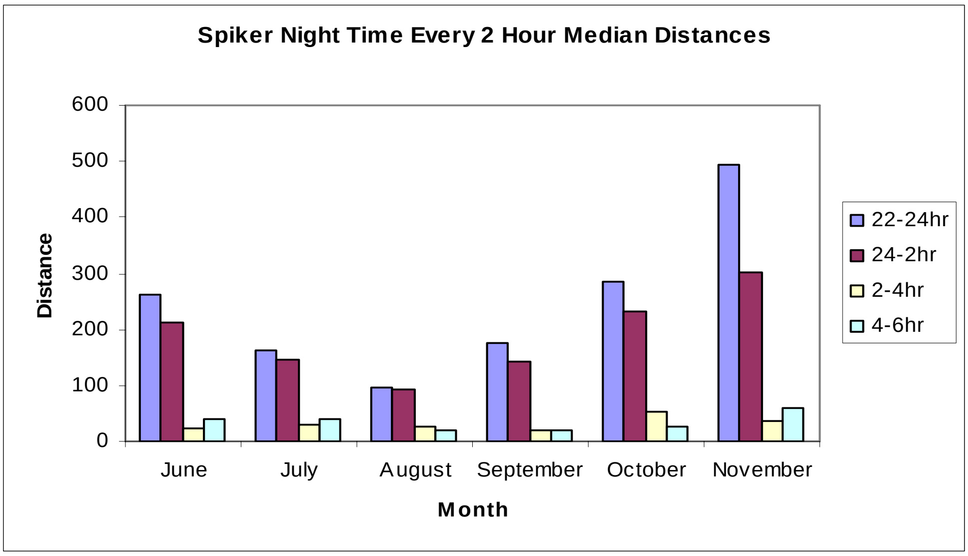


Figure 67 Spiker Night Time Every 2 Hourly Distance

CHAPTER 5 CONCLUSION

New Zealand is more dependent on biosecurity than any other developed country. Its economy and trade are largely based on the exotic species brought here by settlers in the 19th century; and our freedom from major pests and diseases is critical to producing efficiently and trading freely. Almost 60% of New Zealand's exports and 20% of its Gross Domestic Product (GDP) depend on efficient and healthy primary production. Yet New Zealand is vulnerable because of our high level of endemism in our flora and fauna. Pests and diseases brought into the country have the potential to seriously damage natural resources and threaten the economy. Biosecurity is equally important to another special aspect of New Zealand – our relative freedom from pests and diseases that affect human health and welfare.

Biosecurity New Zealand has the lead role in preventing the importation of unwanted pests and diseases, and for controlling, managing or eradicating them should they arrive in the country. Biosecurity New Zealand is passionate in its desire to keep New Zealand free of unwanted organisms, to prevent or reduce any damage these may cause should they occur, and to protect and preserve the land, water, industry and people of New Zealand.

Introduced animals, and those which enter this country as incursions, frequently cannot be controlled to the point of eradication, while many pests already established here continue to cause problems requiring constant vigilance and ongoing control programmes. Habitually, managers lack the financial resources and political commitment to control species to the point of eradication. Policy makers and managers together need to recognize this fact and endeavour to work with it. Eradication is a commitment that should only be considered if the above constituents (financial and political commitment) are in place as well as the ability to place all animals at risk of being killed, be able to kill animals faster than they can reproduce and finally to be able to prevent reinvasion (Parkes, 1993). If these conditions can not be met, the localized control of pests in areas of high production value, biodiversity value, or of significant aesthetic appeal should be considered.

This research used advanced mathematical methods (GAMs) and GIS, GPS techniques to obtain information on deer movement and habitat use. This was to characterize deer movement as it is influenced by climatic variables and particular resource selection used by red deer, which together provides a unique representation of those pathways which are utilised by feral red deer in this particular area in New Zealand. The key results are as follows:

5.1 Land Cover utilization.

The land cover classification scheme for Land Cover Database Version 2 (LCDB2) is a hierarchical development of the target classes used for Land Cover Database Version 1 (LCDB1) (see Table 4, Chapter 4). The LCDB2 used by red deer stag and spiker in this study was divided into three classes, namely, “cover”, “medium” and “open” (see Table 3, Chapter 4).

The red deer stag’s coverage use types at weekly level are significantly affected nonlinearly by month. The “medium” and “cover” use by the stag are significantly impacted by climate, with nonlinear impacts of temperature, and interactive effects of temperature and rainfall. An examination of the spline plots shows that the stag’s open and cover use gradually decreased in winter to a minimum in August (then maximum in October). In contrast, the stag’s medium usage increased steadily during winter to a maximum in August and minimum in July and November. All LCDB2 use types show a highly significant shift with the onset of spring. Only medium usage decreased with the onset of spring, the stag’s cover use increases with increasing temperature to about 5°C (average weekly temperature), remains stable then to 8°C, but decreases above 8°C.

The spiker’s medium use decreases with the onset of spring with a maximum medium use in August, in contrast to a minimum open and cover use by the spiker in August, a similar trend is shown by the stag. The spiker’s open use shows a nonlinear significant impact of weekly average temperature (AT). Open use increases with AT to approximately 5°C, remains stable to 8°C, then decreases above 8°C. This is similar to the stag’s nonlinear temperature thresholds; or, cover usage by the red deer stag.

5.2 Movement Distance (MD)

At the weekly level, the stag travelled long distances in October and November, for high average weekly temperature in excess of 6°C, and high rainfall (greater than 140 mm). Similarly, the spiker also travelled long distances in the same months of October and November, with similar thresholds AT>6.2°C and RF>122.5 mm.

Both the stag and spiker travelled medium level distances (MD) in spring, for above average temperature (4<AT<6°C) for the stag; 2.6<AT<6.2°C for the spiker) and medium to high rainfall (100<RF<140 mm) for the stag; (36.2 <RF<122.5 mm) for the spiker. The red deer stag and spiker travelled short distances in July and August (also June for the stag), this movement profile being associated with low temperature (AT<4°C for the stag; AT<2.6°C for the spiker) and low rainfall (RF<100 mm for the stag, RF<63.2 mm for the spiker).

At a daily level the red deer stag's distance (MD) was impacted on by both temperature and rainfall with a seasonal difference in this interactive effect. Likewise the spiker's distance travelled showed significant interactive effects between AT and RF with type of coverage. In contrast the red deer spiker's daily GAM model for Y=MD showed average daily temperature to be the biggest "driven" of distance interacting with LCDB2 utilisation. Similarly, the effect of AT on stag's distance travelled differed across the two seasons.

5.3 Diurnal patterns

Analysis of coverage at a weekly level with day and night factors show that the red deer stag's medium use differs significantly between day and night and that daytime use of medium cover is significantly higher than night-time access to medium cover. However, the red deer stag's cover use is significantly higher during the night. For the stag, the interactive effect of rainfall and temperature on medium use is significant (P=0.0165), but the same across day and night. September is the month of no or low medium use with associated increased rainfall and increasing temperatures. July is the stag's month of high medium use nocturnally and diurnally. For the stag the interactive effect of rainfall and temperature on cover use differs between day and night (AT*RF*DN, P=0.347) which means the stag uses more cover at night-time than daytime.

Similarly to the stag, the spiker's use of daytime medium cover is significantly larger or more frequent than at night; however the use of open increases with increased temperature more dramatically diurnally to a maximum in November and the spiker's use of cover is similar diurnally and nocturnally, in contrast to the stag's significantly increased access to cover during the night. As with the red deer stag, the interactive effects of rainfall and temperature on the spiker's medium and open use is similar diurnally and nocturnally. The spiker's use of cover overall decreased with increasing temperature (both during night and day) with June and July associated with higher cover. 3D contours delineate the interactive impacts of rainfall (RF) and temperature (AT) on the spiker's daytime access of respectively habitat types (open, medium and cover).

Analysis of weekly distance by day and night, climate, month, season and LCDB2 also shows 1) day time distance travelled by the stag exceeds night time overall, particularly in spring. Indeed for the stag distance is correlated positively with increased temperature both for day and night movement; but only daytime MD is positively correlated with increased rainfall. Maximum distances (MD) travelled by the stag occurs in October and November both for day and night movements. Minimum distance travelled by the stag occurs in winter (July and August) diurnally and nocturnally. 2) The spiker distance travelled is impacted by interactive effects of temperature and LCDB2 coverage. The spiker's distance shows a positive association with average temperature which is highlighted more in spring and by day time.

5.4 Integrated Analysis

Generalized additive model (GAMs) is a relatively recent development that extends standard linear regression to automatically fit non-linear terms. In this study, it was used to model red deer movement as affected by climatic variables (such as temperature and rainfall), land cover use (open, medium and cover) and interactive effects between these factors. The results of GAMs were also confirmed by cross correlation and Friedman tests.

The cross correlation test indicates that weekly distance travelled by the red deer stag is positively correlated with average temperature (AT) for both day movement (r=0.357 (lag 0)) and for night distance travelled (r=0.415 (lag 0)). Indeed increased distance is correlated with increased average weekly temperature for lags of up to 3 weeks prior. The distance travelled by the stag during the day is also positively correlated with rainfall (r=0.418 (lag 0)) during the same week. The stag's night distance is not significantly cross correlated with rainfall. The distance travelled by the red deer stag is also highly correlated with higher "cover" use both by day (r=0.418 (lag 0)) and by night (r=0.547 (lag 0)) up to lags of 2 weeks prior. Nightly distance travelled by the stag is highly positively correlated with "open" coverage (r=0.422 (lag 0)), whereas daily MD is not significantly associated with "open" utilization. The more "medium" coverage utilised by the red deer stag, the less distance travelled at daytime (r=-0.538 (lag 0)) and also at night (r=-0.374 (lag 0)). It seems that the red deer stag seeks out open coverage at night and this may necessitate travelling longer distances. The stag also seeks out "cover" travelling increased distance both diurnally and nocturnally. This is in direct contrast to the red deer spiker for whom decreased distance is associated with "cover" use, both diurnally (r=-0.341 (lag 0); Table 20) and nocturnally (r=-0.297 (lag -1); Table 20). For the red deer spiker increased MD is highly correlated with increased "open" use at both daytime (r=0.846 (lag 0) to lag of 3 weeks prior) and by night (r=0.769 (lag 0); Table 20). The use of both "open" and "cover" by the red deer stag increases with increasing temperature at night (r=0.555, r=0.360). During the day "open" use also increases with increased temperature (r=0.262 (lag 0) up to lag of 5 weeks prior. By contrast "medium" LCDB2 use by the stag increases with reduced temperature, both by night (r=-0.321) and by day (r=-0.193). A similar relationship exists with rainfall, in that, "medium" use by the stag also increases with reduced rainfall, both at night (r=-0.373 (lag -1)) and by day (r=-0.417(lag 0) to lag 2 weeks prior). Whilst there is a positive correlation between the red deer stag's night and day distance (r=0.359) and stag's night and day "medium" use; the use of cover and "open" differ between day and night.

Weekly distance travelled (MD) by the red deer spiker is highly positively correlated with average temperature (AT) for both day (r=0.693 (lag 0) up to lag of 5 weeks prior) and night (r=0.676 (lag 0) up to lag of 5 weeks prior). A similar positive relationship between MD and AT is shown by the stag (Table 19). In contrast to the stag, the spiker's distance travelled is negatively correlated with rainfall (RF), both in terms of day movement (r=-0.213 (lag 0)) and night movement (r=-0.247 (lag 0)). Increased distance travelled by spiker is negatively correlated with "cover" use both by day (r=-0.341 (lag 0)) and during the night (r=-0.297 (lag 1)). This is in direct contrast to the stag's positive relationship between distance travelled and "cover" use. The spiker's nightly and day distance travelled increases dramatically with increased "open" utilization (r=0.769 and r=0.846). For the spiker distance travelled is not significantly correlated to "medium" use, whether by day or night. This is in stark contrast to the stag's movement by day and night, which decreases with increased use of "medium" cover. As with the stag, the spiker's use of "open" increases with increased temperature (r=0.600), in contrast to the stag, the spiker's use of "medium" increases with increased temperature (r=0.301), “cover” use by the spiker decreases however with increased temperature (r=-0.646). Similar to the stag, the spiker’s “medium” use decreases with increased rainfall (r=-0.379 (lag -1). As with the stag, the spiker’s distance travelled by day is positively correlated with night time distance. Increased “open” use at night correlates with increased “open” use by day for the spiker, in contrast to the stag. Likewise, increased “cover” at night is associated with increased “cover” by day for the spiker, not so for the stag.

Friedman multiple comparisons test of the stag day-time two hourly median distance showed a significant ($P<0.0001$) time of day effect of the stag’s movement with the distance travelled between 16:00-18:00 hours being significantly higher than distance travelled by the stag later during the period 20:00-22:00 hours. No significant differences in MD between the other pairwise comparisons of two hourly intervals were found for the stag. The spiker showed no significant time of day effect for MD broken down into 2 hourly intervals.

5.5 Utilization of Technology for Pest Management

GPS collars implemented within GIS and combined with advanced statistical methods is an impressive tool to gain and an understanding of ungulate-vegetation interactions and to allow identification of specific animal pest management problems, providing scope for the integration of multi-species management, which is now a vital means of protecting our environment as well as being important for our economy. Pest control will need to become increasingly safe, humane and cost-effective to remain economically and socially sustainable.

Use of innovative technology— such as Global Positioning Systems (GPS), geographic information systems (GIS) and remote sensing supports the accuracy demanded by the public to facilitate the understanding of animal movement in wildlife management problems; and will act to lessen the resistance towards management operations, which in turn will allow effective assessment of management practices. Researchers will also become better able to monitor pest animals as electronic tracking technology, including satellite tracking, becomes more effective and cheaper.

The combination of all three techniques used in this study illustrates an excellent approach to facilitate management and resource-use interactions, and where necessary to aid in precision requirements for control. A strategically important focus of this technology is to identify points of vulnerability in the major invasive pathways, thus aiding monitoring and control activities.

Remote downloading is an innovative tool for verifying animal whereabouts; however the actual performance of obtaining data is not a fail-safe procedure and in this study transmission quality was poor. As a consequence of this, transmission of data will not be always accurate for all habitat types and animals, particularly in mountainous terrain, in heavy bush or when downloading from within some topographical features. The ability of the collar to acquire fix data in these environments is however not of concern, with GPS components being very effective.

It is important that strategic management uses an understanding of the pest species' biology to develop medium to long-term goals and approaches to pest control. Deer managers and decision-makers are interested in where deer will be in the future, what particular locations will be and what kind of land cover, and climate variables affect deer movement, and so, this research is informative for pest control and management in New Zealand in some extents.

5.6 Future Research

Future research should focus on continuing to improve the understanding of the habitat use and relationship of climate and habitat use to landscape movement of introduced animal pests such as red deer.

The focus should also be upon continuing to inform biosecurity managers so as more efficient use can be made of limited resources.

CHAPTER 6: DISCUSSION

6.1 Red Deer Habitat Selection

Habitat choice is the result of animal decisions that balance the trade-off between predation risk (human disturbances), foraging (resource richness) and climatic factors (Mysterud and Ostbye, 1999; Patthey, 2003). Theoretically, animals should select habitats that minimize the ratio of mortality risk to net energy intake (Lima and Dill, 1990). Such decisions (i.e. leaving a rich place to a safer place) may be linked with the range at which animals can perceive key landscape elements (Lima and Zollner, 1996). Consequently, in this case, several factors may operate on red deer habitat selection.

This research shows that red deer seasonally utilise distinct habitat in terms of LCDB2 types, namely, indigenous forest, deciduous forest and Hardwood forest (cover); broadleaved indigenous forest, Gorse and Broom, Manuka and or Kanuka (medium); and alpine gravel and rock, depleted tussock grassland, low producing grassland, river and lakeshore gravel and rock, tall tussock grassland (open) (see Table 3, Chapter 4 for full description) within a landscape (at the home range scale) more frequently than others at daily and weekly levels, and diurnally and nocturnally. The red deer stag and spiker's open and cover use gradually decreased in winter to a minimum in August (then maximum in October). The medium usage increased steadily over winter to a maximum in August and minimum in July and November. All LCDB2 use types show a highly significant shift with the onset of spring, only medium usage decreased with the onset of spring.

However, Nugent et al. (1997) found deer made greater use of woody species in autumn and winter. Although the use of broadleaf did not differ seasonally, lancewood and kamahi use was higher in autumn and winter and lower in spring and summer. The most notable seasonal difference was a threefold increase in fern use between winter and summer, which was largely due to increased use of *D. squarrosa* and *B. fluviatile*. Diet changed significantly between seasons, and the patterns of seasonal change were generally the same in all three habitats. Use of tree foliage typically peaked in winter and was lowest in summer (Nugent, 1990).

Table 31 Findings of Deer Habitat Selection

Author	Deer Seasonal Habitat Selection
Allen, A. W. and Jordan, P.A. Washington, DC (USA), 1987	Winter: Forest
Berg, W.E. and R.L. Phillips, Minnesota (USA) 1974.	All seasons: shrublands
Bergstrom, R. and O. Helford.Europe and Poland.1984.	All seasons: shrublands
Boonstra, R. and A. R.E. Sinclair, British Columbia, Canada, 1984.	Winter: coniferous forests
Cobb, M. A, Voyageurs National Park (Canada), 2004.	Winter: Forest
Eastman, British Columbia (Canada), 1977.	Winter: coniferous forests
Irwin, G. Minnesota, (USA), 1975.	Winter: Forest
Kelsall and Telfer, North America, 1974.	Winter: Dense conifer forest
Ludewig, H. A. and Bowyer, T. Maine, (USA), 1985.	Winter: Forest
Matchett, M.R. Montana (Canada), 1985.	Winter: Dense conifer forest
Nugent, G. and Challies, C. N. Stewart Island (NZ), 1988. Nugent, G.; Fraser, K.W and Sweetapple, P.J. Waihaha Catchment, Pureora Conservation Park. (NZ), 1997.	Spring: shrub/forest Summer: shrub/forest Autumn: shrub/forest Winter: shrub/forest Summer: Fern Autumn: Forest Winter: Forest
Patthey, P. Switzerland and France, 2003.	Winter: Forest
Peek, J. M., Urich, P. L., and Mackie, R. J. Minnesota **(** USA) 1976.	Winter: Forest
Phillips, R.L., W.E. Berg and D.B. Siniff, Minnesota (USA), 1973.	Early winter: Open stands Late winter: timber
Pierce, D.J. and J.M. Peek. (USA), Idaho (USA), 1984. Pierce, J.D. Idaho, (USA), 1984.	Winter: Old growth forest Winter: Dense conifer forest
Proulx, L.L ,Quebec, (Canada), 1983	Winter habitat: Forest
Simpson, K., J.P. Kelsall and C. Clement. Revelstoke, B.C. (Canada), 1988.	Early winter: open shrublands, burns and clearcuts Mid-winter: forest
Thompson, I.D. and M.F. Vukelich, M.F, Ontario, Canada, 1981	Winter: conifer forest
Vanballenberge and Peek, Minnesota, (USA), 1971	Winter: conifer forest

Most of the material consumed by deer was classed either as adult foliage (either green "fresh" leaves (56% of annual diet) or older yellowed senescent leaves (24%)) or as stems (12%) (Nugent, et al., 1997). Deer obtained most woody-plant foliage as litterfall (Fraser, 1991; Nugent, 1990; Nugent, 1993; Nugent and Challies, 1988; Nugent and Fraser, 1993). For broadleaf, the main food, 70% consisted of yellowed leaves (93% in summer and 55% in winter). For lancewood, 53% of the leaves eaten in summer were yellowed (cf. <1% of those eaten in winter). For lancewood and pokaka, the green leaves consumed were obviously from above the browse tier because they were almost always of adult rather than juvenile form. Partly digested and unidentifiable fibre (7%) was probably also of leaf or stem origin (Nugent *et al.*

suspect mostly from lancewood leaves or grasses because these foods were typically present in samples with larger amounts of unidentifiable fibre). Small woody seedlings, fruit, and other material (such as fungi) each comprised <1% of annual diet. All of this indicates a strong preference for woody vegetation, although this may reflect the relatively unavailability of different habitat in this area of study.

Cobb (2004) found by compositional analysis that both moose and white-tailed deer exhibited a strong preference for the spruce/balsam fir habitat type at the home range scale. Proulx (1983) found that White spruce and balsam fir were among the dominant overstory species in moose winter yards in southern Quebec. Balsam fir is an important source of forage for moose in boreal forests, especially during the winter season (Allen and Jordan, 1987; Irwin, 1975; Ludewig and Bowyer, 1985; Peek, et al., 1976). Winter habitat are situated in beech forest in lower altitudes, Moose showed a significant preference for spruce/balsam fir over all other habitats except the shrubland alliance and bur oak types at the home range scale. Shrubland alliance, aspen/birch, herbaceous alliance, bur oak, and red/white pine habitat types all tied for second in preference and did not differ significantly in preference from one another. White-tailed deer selected spruce/balsam fir over all other vegetation types except the aspen/birch at the home range scale. Aspen/birch was significantly preferred to all remaining vegetation types except the herbaceous alliance. Jack pine and bur oak tied for lowest in white-tailed deer preference at the home range scale (Patthey, 2003).

In a study by Patthey (2003), it was found selected and avoided species varied between seasons according to plant phenology, except for conifers and ferns, which were always avoided. The intermediate feeding style of the red deer was confirmed, with concentrate foods (broad-leaved trees and seedlings, shrubs, forbs and legumes) being selected from the spring to the autumn, followed by a switch to grass during the winter. The hinds selected grass in the winter since it was a highly available and relatively "high quality" forage at that time (Dumonta, et al., 2005).

Red deer selection of habitat is mostly linked to the availability of food, but other factors such as weather and fly infestation can also influence movement. In an early study using this data, slight preferences were found for beech forest, high scrub, and tussock/grassland, and slight avoidance exists for improved grassland (McKenzie, 2004). The stag was found to have preference for improved grassland, low scrub, scrub/tussock and tussock/grassland, in contrast the spiker, preferred (used greater than proportionally available) beech forest, high scrub, and tussock/grassland. All of these studies, albeit in different landscapes, with different habitat assemblages, show that deer partition and selectivity utilize different parts of their respective home ranges. This current study further shows that climatic variables are a significant factor in that selective utilization of habitat.

6.2 Animal Movement

Deer movement is governed to a great extent by the availability of food. As food sources become depleted in the autumn deer are forced to travel greater distances to locate new food sources. They often shift their feeding patterns to take advantage of preferred foods that ripen or become available during the time. Depending on how scattered these available or preferred food sources are, and how close they are to individual deer core areas, the deer may move more, or less, than normal. This "Distance Factor" is directly linked to the "Food Factor" and these two together, because of their importance to deer survival, can affect how much time is devoted to other fall deer activities (Michels, 2005).

This research shows the stag and spiker travelled long distances in October and November for high average weekly temperature in excess of 6°C, and high rainfall (greater than 140 mm). Both the stag and the spiker travelled medium level distances (MD) in spring and short distances in July and August (also June for stag), this movement profile being associated with low temperature and low rainfall. Cross correlation also confirms that the spiker's distance is inversely correlated with rainfall; Time series analysis shows both the stag and the spiker increased travel in June, October and November which perhaps reflects feed requirement and feed availability. It was shown that the stag is much more fast-moving and more active than the spiker overall. A similar result was found that during cold weather deer move less because cold temperatures cause them to lose body heat (Michels, 2005). However, when prolonged cold weather keeps deer from feeding regularly or when low food sources and cold weather cause them to lose body condition, they are forced to move and locate food. They often move during the warmest part of the day, usually in the late afternoon or early evening, especially if there is cloud cover that may keep heat from dissipating. When food sources are scarce, especially after agricultural crops have been harvested, grazing plants have been depleted and mast and berries are gone, deer are forced to rely primarily on browse. If other preferred food sources are available, deer will use them until they are depleted and then will search for another source. Limited food sources in late fall/early winter often concentrate the deer, including older trophy-class bucks, on the food sources. In seeking to avoid lower night temperature and to catch the warmth of the sun during the day in winter, deer usually need to travel long distance (Lentle and Saxton, 1991).This finding contrasts with our results. However, this study shows that stag started increased travel in June (June was the month of release), which may reflect that the stag needs to get orientation to the new environment and find available habitat to use. In July and August, stag deceased travel to reduce energy loss so as to maintain their body weight. As results, they usually keep in sunny sheltered spots, feeding little because of food scarcity. Some recent work has been proved on the mechanisms that Deer have an internal regulatory mechanism that reduce their appetite in winter, so that they lose weight do not feel hungry. The consequent reduction in the constant quest for food enables deer to live during winter in quite small areas (Lentle and Saxton, 1991).

Deer movement is affected by temperature and as such there will be a decline in deer movement during winter (Dumonta, et al., 2005). The results found here are consistent with previous findings and provide a new insight into the role of habitat features in thermoregulation. In temperate climates, red deer survive cold winters with low food availability (Patthey, 2003), however deer may reduce their activity to limit energy loss. Lowering heat loss during winter seems to be essential for red deer. Since height, canopy closure, stem density modified temperature, wind speed, precipitations and solar radiations within stands (Cook, et al., 1998), bedding sites might be also chosen for their quality in energy conservation. Chen et al. (1999) had found that red deer use more frequently denser coniferous shelter. All these result have been explained as thermoregulation-linked behaviors. A high and dense coniferous cover (protection against precipitation, reduction of radiant heat loss) is not necessarily always an advantage for ungulates. Cook et al. (1998) found no positive effect of high coniferous cover on domestic elk-cows. This result consistent with our results on winter movement patters.

6.3 Red Deer in Cultural Landscapes

Deer are classed as wild animals in Canterbury under the Wild Animal Control Act 1977 even when held in captivity for the purposes of farming. Section 12A of the Wild Animal Control Act empowers the Minister of Conservation to specify, by Gazette Notice, where the farming of the different species of deer is allowed or prohibited, and to set perimeter fence standards for deer farms. Sections 12A and 12B contain provisions for the management of deer in a safari park or game estate. Feral deer are also declared animal pests in the Auckland Regional Animal Pest Management Strategy (ARC, 2002). The Auckland Regional Council aims to protect Auckland's areas of high conservation value from the impact of deer grazing and browsing, and to make people aware of the damage that deer can do. The Auckland Regional Council will only carry out deer control operations where the priority for deer control exceeds or equals the priority for possum control (ARC, 2002).

Both animal pests and wild animals pose threats to natural values in Canterbury (DOC, 2000). For example, feral deer, which adversely affect indigenous ecosystems through grazing and can reduce production by damaging crops and exotic forests. They have also been implicated in the transmission of bovine Tb. They are therefore a potential threat to our Regions agricultural industry. Feral deer threaten areas of indigenous forest in the Region through over browsing and they also cause damage to root and maize crops, bruise young trees and strip bark in forest plantations.

However, some wild animals have significant commercial and recreational values. Wild deer will continue to be valued as a recreational and commercial hunting resource as they will have high value in environment and ecology although their cultural and ecological values are low at present. The basic management principles and control techniques are identical to both animal pests and wild animals. These are (DOC, 2000):

1) prioritising management on the significance of the actual or potential impacts of the pest or wild animal on identified natural values;
2) controlling on the basis of achievable goals with present resources and technology;
3) the level of control applied must be the method that is best able to meet the natural values threatened;
4) areas for control will be managed as discrete management units;
5) The Department will control wild animals where recreational and commercial hunting is insufficient to maintain natural values.

There are issues that require additional management resources include:

1) monitoring the trends of deer in alpine grasslands and beech forests;
2) managing recreational hunting areas (RHAs) in accordance with national

policy;

3) gazetting areas for permitting or prohibiting deer species;
4) authorising safari hunting.

The results reaffirm much of what is known about red deer habitat selection, seasonal movement patterns, offer known insights, and emphasize that habitat selection and movement are complex processes within which a lot of factors interact with one another. Habitat selection models that provide information on the relationship between wild animals and parts of the landscapes in which they live can benefit management of control operations (Cochrane, 1999). Cochrane (1999) proposed that habitat models are not models of carrying capacity, instead they attempt to quantify habitat in terms of its suitability to particular animal species; Habitat models act to focus attention on both the pest and the resource at the same time, thus allowing better management decisions, especially habitat selection models would help control programs through their ability to provide a surveillance tool and a post-operational monitoring tool.

The study analysed different patterns of habitat use between seasons, weeks and day selection level. Application of these models in natural resource management and conservation planning are consequently complex as they need to account for the entire combination of ecological factors which vary by scale and season, to offer the best combination of food and movement in the special area.

There are several factors that determine when and where deer move during the winter and spring. An understanding of these factors will aid in wild deer management and control. Fargione, et al. (1991) found that whether or not a particular plant species or variety will be eaten depends on the deer's previous experience, nutritional needs, plant palatability, seasonal factors, weather conditions, and the availability of alternative foods. The increasing economic potential of white-tailed deer on private lands in Texas indicates a need for more detailed information about deer habitat requirements. Especially needed is information on the amounts of forage deer require and kinds they prefer, the seasonality of their feeding habits, and the effects on deer foods following control of rangeland vegetation. Identifying desirable deer forage could be of primary importance in land-use planning that is compatible with production of quality deer (Leroy, et al., 1979).

Our model provides a statistical and mathematical relationship between climatic variables and animal movement distances, and habitat selection. Modeling procedures may also reveal potentially important ecological factors that can be further investigated, such as wind, sunlight etc. Knowledge of the movement patterns of red deer in such a landscape is important in developing management strategies and assessing results of management programs. It also provides an approach based on deer feeding preferences to wild deer control in New Zealand.

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